IMPERIAL BUREAU
21 AUG. 1930
OF MYCOLOGY

PLANTERS' RECORD

VOL. XXXII

IMPERIAL BUREAU
15 FEB 1929
OF MYCOLOGY

A quarterly paper devoted to the sugar interests of Hawaii, and issued by the Experiment Station for circulation among the plantations of the Hawaiian Sugar Planters' Association.

JANUARY TO DECEMBER

THE HAWAIIAN PLANTERS' RECORD

VOL. XXXII

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IMPERIAL BUREAU OF MYCOLOGY 15 FEB 1929

ORGAN OF THE EXPERIMENT STATION OF THE HAWAIIAN SUGAR PLANTERS' ASSOCIATION

HONOLULU

1928

THE HAWAIIAN PLANTERS' RECORD

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Notes in Reference to the Introduction and Distribution in Hawaii of Yellow Caledonia and Rose Bamboo Canes

By Walter M. Giffard
(*Honorary Member of Hawaiian Sugar Planters' Association*)

In 1876, the writer held a clerical position with the late firm of W. G. Irwin and Company, then a copartnership, consisting of John S. Walker, Z. S. Spalding and William G. Irwin.

At this period the lowland canes were mostly, if not altogether, the Lahaina, and the upland fields were planted with the so-called native varieties. In Kau, I believe that the latter predominated on the lower as well as the upper lands.

General interest in new varieties was not altogether lacking, but it was not until 1879 or 1880 that concerted effort was made to introduce foreign varieties for experimental purposes.

Because the origin of our cane varieties is of deep interest to all concerned in the Hawaiian sugar industry, it is important to record for future reference the recollections of those who were connected with the industry in its earlier years.

The following contribution deals with the introduction of the two varieties of sugar cane known as Yellow Caledonia and Rose Bamboo, about 1880, and the subsequent distribution of the first named variety to replace the then standard Lahaina. Lahaina, even at that time, nearly fifty years ago, was suspected to be gradually deteriorating in certain localities because of attacks of what was then known as Lahaina disease, now called root-rot.

W. G. Irwin and Company were agents, at that time, for two independent sugar plantations in Kau, the Hilea plantation and the Hutchinson plantation, both of which cropped only the so-called Hawaiian varieties. Charles N. Spencer, the manager of Hilea, an enthusiastic collector of native canes, developed a sudden yearning to add to his collection some foreign varieties, for experiment and comparison. To this end Spencer secured the personal cooperation of John S. Walker, then the senior partner of the firm of W. G. Irwin and Company, and prevailed upon Walker to procure for the Hilea collection a selection of some

of the best commercial varieties of cane grown in Queensland, Australia, in the hope that among these introductions there might be something that would eventually lead to a heavier production of sugar in Kau.

In due course, a selection of sticks of Queensland cane, comprising about twelve varieties, if I remember rightly, came consigned to W. G. Irwin and Company.

I have a distinct recollection of the receipt of this consignment and, in my clerical capacity, forwarding the package to Manager C. N. Spencer on one of T. R. Foster and Company's schooners at that time (1880-1881) freighting between Honolulu and the Kau ports.

Later, reports in Kau were to the effect that amongst the Queensland canes introduced, were two very promising varieties known at Hilea and Hutchinson plantations as Yellow Caledonia and Rose Bamboo. Word came to the Honolulu office that both these varieties were making an exceptional appearance alongside the native canes on Spencer's experimental plots.

Hilea plantation, in the meantime, had been incorporated as the Hilea Sugar Company, its stock owned entirely by W. G. Irwin and Company. After the death of Alexander Hutchinson, our firm bought his plantation and incorporated it. The Hutchinson mill was then at Naalehu. After Irwin and Company acquired the two places, they erected a newer and larger mill at Honuapo to grind the cane from both Hilea and Hutchinson, merging all of the sugar properties in the Hutchinson Sugar Plantation Company and discontinuing operation of the Hilea and Naalehu mills. While this was in progress, Honuapo had become the chief shipping port at the south end of the island.

The late John A. Scott, of Wainaku, Hilo, was the engineer in charge of the erection of the Honuapo mill. He continued as engineer until the owners transferred him to Hilo as manager of Wainaku plantation, which later became the Hilo Sugar Company, Limited.

While he was employed at Honuapo, Scott knew of Spencer's hobby of collecting and growing cane varieties. Later, when visiting there, he took note of the outstanding qualities of some of the new canes, especially the Yellow Caledonia. In many of his letters to W. G. Irwin and Company, written from Hilo, Scott, in discussing the need of better varieties, illustrated his theories by referring to the steady weakening of Lahaina cane at Waiakea's fields, near by.

He became much concerned over the possibility of the Lahaina disease spreading to the Wainaku fields from Waiakea and asked our office at Honolulu to get a few bags of Yellow Caledonia for him from Hilea, his idea being that if Lahaina should show signs of failure he would have another variety with which to replace it.

In consequence, a shipment of Yellow Caledonia seed cane was forwarded and in due course Scott planted quite an area with it. He in turn distributed cuttings to other plantations in the Hilo district. Later, seed of both Rose Bamboo and Yellow Caledonia were sent direct from Hilea to a number of other plantations, including Waimanalo, on Oahu. Waimanalo, I think, was the first plan-

tation on this island to get Rose Bamboo. I distinctly recollect the first shipment to us, after W. G. Irwin and Company became agents for this plantation.

This together with the following statements fixes the time of the introduction of these two canes from Queensland, Australia, as in the year 1880, by W. G. Irwin and Company, for C. N. Spencer at Hilea; and the first shipment of Yellow Caledonia to Wainaku about 1890; and the first commercializing of this variety by Hilo Sugar Company.

At this late date there is no documentary evidence to prove my contentions as to the way in which these two varieties of cane first reached Hawaii. However, I submit the testimony of three men who were cognizant of the facts, viz.: the personal recollections of Ned Robbins, who was a cane planter and head overseer at Hilea and Naalehu from 1877; of Harry V. Patten, formerly bookkeeper at Hilea; and of H. Jensen, a luna at Hutchinson plantation in 1885. Their testimony forms an interesting contribution to the history of the sugar industry in Kau, and is appended herewith:

1. Letter from Harry V. Patten to W. M. Giffard, dated Hilo, May 1, 1926.

The other day I met a man (H. Jensen) who worked for years at Naalehu, and in talking with him, he told me that he went to Hutchinson Plantation in 1885. . . He is about the last of the old crowd formerly there; was a mule luna for years, and his word can be given full credence.

Under date of May 20, 1926, in answer to further correspondence, Mr. Patten again wrote:

Mr. Jensen is thoroughly reliable and knows what he is talking about. At present he is a sick man and will probably not live long. Mr. Robbins is the only one left who could make a statement of any value.

I had already obtained the following testimony from Mr. Robbins, in 1923, when I interviewed him at his home. My notes, taken at the time of the interview, are as follows:

Mr. Robbins: I began planting cane at Hilea in 1877. The plantation was then called "Hilea plantation." It was incorporated later under the name "Hilea Sugar Company," and afterwards was merged into the Hutchinson Sugar Plantation Company.

I was head luna at Hilea plantation under the late Charles N. Spencer for some years, beginning in 1877, and later was employed as head overseer by the Hutchinson company. The Hilea mill foundations were begun in 1878. They were constructed by John Bowler. The mill was erected shortly afterwards.

C. N. Spencer, the manager, was formerly overseer and planter with Alexander Hutchinson at Waiohinu. He had been previously in the pulu business with George W. C. Jones, both Spencer and Jones having lost most of their pulu while it was stored for shipment at Punaluu, Kau landing, during the big tidal wave and volcanic outbreaks from the slopes of Mauna Loa.

Through J. S. Walker, of the firm of Irwin and Company, Spencer was appointed manager of Hilea plantation from its inception. Spencer was much interested in collecting Hawaiian canes as a hobby, and had quite a number of varieties planted at and near Hilea and at Waiohinu, while I was in the district. I know of his having written Walker for some cane varieties from Queensland, Australia.

During my stay in Kau I kept a plantation diary for some years and noted therein special work and events as they happened, but unfortunately during my recent illness this diary and other papers that were in a way important to me, were inadvertently burned by members of my family while cleaning up the house. As a result I am not positive as to dates, but have clear recollection of the matters you have reference to. I recollect when a box of several varieties of what I was told was Queensland cane came consigned to Spencer. It was about 1877 or perhaps 1878—I am not sure—it may have been a year or two later. I also recollect Spencer sending a consignment of 15 or 20 varieties of Hawaiian canes to Wm. G. Irwin and Company, for exhibition at an agricultural show held at Honolulu in 1878, and that these received a prize.

My remembrance is that the Queensland canes came in large sticks and that our so-called Yellow Caledonia and Rose Bamboo were among the varieties received. Some years later I also remember putting up samples of the Yellow Caledonia variety which were intended for Wainaku plantation in Hilo. Later, further lots were sent to Wainaku and other plantations. I think some was sent also to Hakalau at the request of W. G. Irwin and Company.

The following is a copy of a letter dated Olaa, May 19, 1926, by H. Jensen to Harry V. Patten, which the latter loaned me. Patten was bookkeeper at Hilea Plantation during a part of the period referred to:

H. Jensen, witnessed by Mrs. Puuheana Jensen: With reference to my conversation with you I desire to make the following statements regarding the introduction of Yellow Caledonia and Rose Bamboo into the Hawaiian Islands:

In 1885, I was employed as a luna on the Hutchinson plantation at Naalehu, Kau, Hawaii, and remained in its employ some years. My work often took me to the neighboring section at Hilea, then managed by the late Charles N. Spencer. Mr. Spencer had a fad for collecting many varieties of sugar cane. I remember that on the adjoining land of Wailau he had at least 16 varieties, from which some, later on, were selected for distribution in the district, while others already had been planted elsewhere on his land.

Amongst the promising canes I remember most particularly the three varieties, Yellow Caledonia, Rose Bamboo and Whitney Bamboo. Mr. Spencer claimed that about five years previous, about 1880, he had received a collection of Queensland canes from his Honolulu agents, W. G. Irwin and Company, which they, at his request, had sent to Queensland for, to add to his collection, and that among these there were what we called Yellow Caledonia and Rose Bamboo varieties.

Mr. Spencer also claimed at that time that he grew the so-called "Whitney Bamboo" from the tassel seed, but whether his statement as to this was correct or not, I am not sure.

I am sure, however, that Yellow Caledonia and Rose Bamboo canes were growing in small areas in 1885 on the land of Wailau, at Hilea plantation, Kau; that these canes had been growing there for some time previous; and that some years after 1885 the first consignment of Yellow Caledonia seed was sent to Wainaku, Hilo, from Hilea, by Mr. Spencer, at the request of Wm. G. Irwin and Company, who were also agents for Wainaku plantation, now Hilo Sugar Company.

There is one more brief note to append. The late John A. Scott always claimed that he got his first seed from Hilea in 1890, which corroborates my own recollections. The following, from the files of the Hilo Tribune of April 10, 1897, under the caption, "Earlier Days in Hilo," undoubtedly had reference to some later sample shipments which were sent to W. G. Irwin and Company, for distribution elsewhere than to Wainaku:

William G. Irwin, of Honolulu, is in receipt of several excellent samples of Yellow Caledonia cane grown on Hutchinson plantation in the Kau district on the island of Hawaii.

The Eye Spot Infection Index and Tolerance Index of Seedlings Tested to Date

The Hawaiian Planters' Record for October, 1926, contained an article entitled, "A Method of Testing Cane Varieties for Eye Spot Susceptibility and Resistance," by H. Atherton Lee, J. P. Martin and C. C. Barnum. In this article the methods used in determining the eye spot infection index as well as the eye spot tolerance index of new seedlings were described. With these tests the eye spot resistance or susceptibility of any seedling may be determined in ten days time with very accurate results. Such tests are extremely useful in establishing the eye spot index of newly introduced canes.

Since the publication of this article in the *Record*, many more seedlings other than those reported in the above article have been subjected to similar tests. The object of this report is to present a complete list of all seedlings tested to date, including those seedlings previously reported on as well as those tested since October, 1926.

The methods employed in these tests may be briefly described as follows: All determinations are based on inoculation tests of eye spot susceptibility of cut stalks of the various varieties. These cut stalks are placed in a sulphurous acid solution (1 part of sulphurous acid in 3300 parts of water, as developed by J. A. Verret and his associates). Ten stalks of each variety as well as ten stalks of H 109 controls were used in each test. Usually 5 to 7 varieties were tested at the same time in a large moisture cage. Eye spot spores from pure cultures of the fungus *Helminthosporium sacchari* Butl. were sprayed on all foliage uniformally. At the end of 10 days the total number of eye spot infections as well as the total length of all lesions and the resulting runners were determined. From these figures the accompanying tables were derived.

In Table I, the eye spot infection index of each seedling tested is given. The various seedlings are placed in order of their resistance as compared to H 109, with the most resistant listed first.

In Table II, the eye spot tolerance index of each seedling is given. Here again the seedlings are placed in order of their tolerance as compared to H 109, with the most tolerant seedling listed first. More than one test was made on a great number of seedlings and the number of tests conducted on each seedling is noted in Table II. In such cases where more than one test was made the eye spot infection index and tolerance index presented in Tables I and II are the averages of the results on each seedling.

The arrangement of the seedlings in Table II has more commercial value when selecting a seedling that is to be planted in an eye spot locality. The number of individual infections on one variety may be the same as or even greater than on another variety, but if long streaks or runners are produced on one and not on the other, then the variety without the runners has far greater resistance than the other. Any seedling with a tolerance index of 500 or less may be regarded as commercially resistant to the eye spot disease. A seedling with a tolerance index

TABLE I

EYE SPOT INFECTION INDEX

1–100	Infection Index No.	100–250	Infection Index No.	250–500	Infection Index No.	500–750	Infection Index No.	750–1000	Infection Index No.	1000	1000 +	Infection Index No.
P.O.J. 213	2	Waipahu 36	161	Waipahu 30	251	Waipahu 31	509	H 9923	768	H 109	McBryde 1	1001
P.O.J. 234	3	Yel. Cal.	174	H 8994	261	H 8942	511	H 8988	775		25–C–22	1005
Uba	34	20–S–16	174	Kassoer	266	U.D. 1	531	25–C–9	785		25–C–17	1015
Badila	36	P.O.J. 2727	180	H 8993	275	Wailuku 11	532	25–C–8	800		25–C–10	1061
P.O.J. 979	73	P.O.J. 36	181	Yel. Tip	287	D.I. 52	539	Paia F	860		McBryde 5	1099
		Makaweli 3	183	H 8965	289	H 86484	540	McBryde 3	869		25–C–13	1129
		Waipahu 51	185	H 8961	343	Paia 186	549	25–C–6	879		H 8906	1132
		Waipahu 89	214	Waipahu 81	357	H 81360	608	25–C–12	885		H 86441	1216
		25–C–15	247	H 8952	360	25–C–14	682	Paia 180	901		25–C–5	1441
				P.O.J. 2714	387	Makaweli 476	682	B.H. 10/12	913		Wailuku 8	1575
				25–C–1	405	25–C–11	686	H 89102	915		25–C–19	1756
				25–C–3	419	25–C–16	717	Wailuku 3	921		Ewa 628	1935
				S.W. 3	429	25–C–4	745	Wailuku 2	923		Ewa 800	1938
				Waipahu 35	451			25–C–21	929		Ewa 371	2356
				P.O.J. 2725	493			Paia D	931		Ewa 580	3034
								25–C–20	959		Ewa 57	3097
								Paia 75	960		25–C–18	3599
								McBryde 4	968			
								Onomea H 109 self	985			
								25–C–7	991			
								Paia 150	997			

TABLE II

EYE SPOT TOLERANCE INDEX

0.1–100	Tolerance Index No.	No. Tests Made	100–250	Tolerance Index No.	No. Tests Made	250–500	Tolerance Index No.	No. Tests Made	500–750	Tolerance Index No.	No. Tests Made	750–1000	Tolerance Index No.	No. Tests Made	1000	1000 +	Tolerance Index No.	No. Tests Made
P.O.J. 213	.10	3	H 81360	132	2	25–C–11	253	1	25–C–20	504	1	McBryde 4	816	3	H 109	Makaweli 476	1089	1
P.O.J. 234	1	3	25–C–6	149	1	25–C–21	273	1	Wailuku 11	523	3	Onomea H 109 self	826	1		Ewa 800	1104	1
Badila	7	2	25–C–3	156	1	P.O.J. 2727	300	3	25–C–13	567	1	H 96441	837	3		25–C–19	1125	1
Waipahu 51	12	1	25–C–1	180	1	25–C–12	325	1	H 89102	574	1	25–C–17	879	1		McBryde 1	1149	2
Uba	14	2	P.O.J. 2714	186	3	H 8965	342	2	B.H. 10/12	588	3	Wailuku 29	890	3		Paia D	1177	2
Waipahu 30	15	1	25–C–16	188	1	D.I. 52	351	3	25–C–7	670	1	Wailuku 2	896	3		Wailuku 8	1203	3
Waipahu 36	18	1	Kassoer	188	3	P.O.J. 2725	366	3	25–C–9	670	1	H 8906	921	1		Ewa 628	1250	1
P.O.J. 979	40	3	Waipahu 31	192	1	H 8942	381	2	McBryde 3	674	3					Paia F	1260	2
Makaweli 3	45	3	P.O.J. 36	211	3	Paia 186	384	2	H 9923	696	3					25–C–5	1269	1
H 8993	47	1	25–C–14	225	1	H 86484	404	3	25–C–10	706	1					Ewa 580	1345	1
Waipahu 35	48	1	S.W. 3	243	3	25–C–4	409	1	Paia 180	709	2					Paia 150	1455	2
H 8961	57	1				25–C–22	431	1	25–C–8	726	1					25–C–18	1890	1
Yel. Cal.	59	1				H 8988	444	1								Ewa 57	1922	1
Yel. Tip.	62	2				U.D. 1	453	3								Ewa 371	1938	1
Waipahu 89	69	1														McBryde 5	2397	1
25–C–15	70	1														Paia 75	2720	2
Waipahu 81	71	1																
20–S–16	72	2																
H 8994	77	3																
H 8952	82	1																

between 500 and 1000 should never be planted in bad eye spot areas, but may be planted where eye spot is never considered a serious problem. No eye spot areas should be planted with seedlings with a tolerance index of 1000 or more.

The majority of canes tested show a higher degree of resistance to eye spot than H 109. Some of the seedlings, such as P. O. J. 213, 234, 979, 36, Badila, Uba, Yellow Caledonia and Kassoer, possess outstanding resistance to the disease.

J. P. M.

P. O. J. 36

P. O. J. 36 alongside D 1135 at Mountain View, Olaa; the larger cane at the right is the Java seedling propagated in 1897, and imported into Hawaii in 1923 as one of the first group of canes that gained entrance to the Territory when the custom of prohibiting cane introductions was modified to permit the entrance of certain varieties that had undergone quarantine at Washington, D. C.

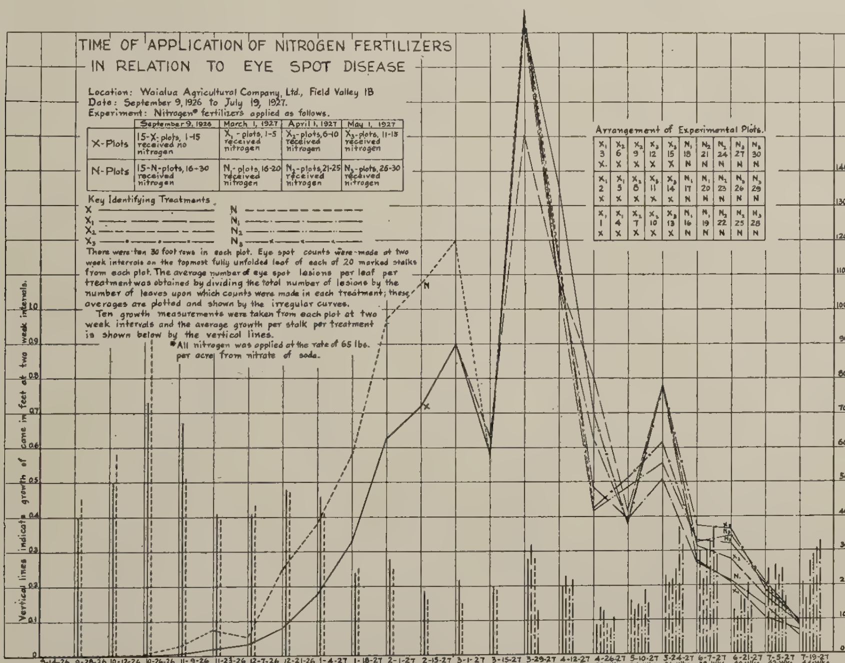
The Time of Application of Nitrogen Fertilizers in Relation to Eye Spot Disease

By J. P. Martin and H. Atherton Lee

Our present data from experimental results have repeatedly shown that late fall applications of nitrogen fertilizers to those fields subject to eye spot, increased the disease very materially. To prevent this increase of the disease, applications of nitrogen fertilizers should be avoided, if possible, in the fall months, or the amount of nitrogen applied at that time should be greatly reduced.

To determine the optimum time in the early spring months to apply nitrogen without materially increasing the disease, the following experiment was planned and conducted during the eye spot season of 1926-1927, in Field Valley 1B, of the Waialua Agricultural Company, Ltd. This experiment extended over a period of forty-four weeks or from September 9, 1926, to July 19, 1927.

Field Valley 1B was planted to H 109 cane July, 1926, and an area of sufficient size for the experiment was selected previous to the time of any application of fertilizers by the plantation. In the early part of September, 1926, 30 plots of 10 rows of cane each were laid out in the selected area. Each row was 30 feet in length, and each plot was 1/28th of an acre in area. The arrangement is shown in the upper part of the accompanying illustration.



The number of eye spot infections was counted at two-week intervals on the topmost, fully unfolded leaf of each of twenty marked stalks in each plot. The average number of eye spot lesions per leaf per treatment was then obtained by dividing the total number of lesions by the number of leaves upon which counts

were made in each treatment; these averages were then plotted as shown in the illustration.

At two-week intervals growth measurements were made on each of ten stalks in each plot. The average growth per stalk per treatment was computed from these measurements and plotted at two-week intervals as shown by the vertical lines on the graph. Each vertical line represents a different treatment.

The applications of nitrogen to the experimental areas were made at various times and may be best presented in the table. All nitrogen was applied at the rate of 65 pounds per acre in the form of nitrate of soda.

Showing Time of Applications of Nitrogen to the Various Series of Plots in Experiment 1

X-PLOTS	September, 1926 15-X-plots, 1-15 received no nitrogen	March 1, 1927 X-plots, 1-5 received nitrogen, 65 lbs. p. a.	April 1, 1927 X_2-plots, 6-10 received nitrogen, 65 lbs. p. a.	May 1, 1927 X_3-plots, 11-15 received nitrogen, 65 lbs. p. a.
N-PLOTS	15-N-plots, 16-30 received nitrogen, 65 lbs. p. a.	N-plots, 16-20 received nitrogen, 65 lbs. p. a.	N_2-plots, 21-25 received nitrogen, 65 lbs. p. a.	N_3-plots, 26-30 received nitrogen, 65 lbs. p. a.

It is interesting to note the amount of cane growth as recorded between the dates of October 12 to October 26, 1926; the plots which had received nitrogen averaged a longitudinal growth of 10.92 inches per stalk as compared to 8.76 inches per stalk for plots receiving no nitrogen. However, the plots receiving nitrogen, with a few exceptions, did not register as much growth in subsequent weeks as the control plots. The cane in both treatments of this experiment made very good growth during the winter months, especially up to January 4, 1927, and after that date the growth of the cane was quite uniform to March 29, 1927. The smallest amount of growth was recorded during the latter part of April which was the month when the most rainfall occurred during the experiment. The extra amount of nitrogen fertilizer in this experiment did not give a marked increase in growth during the winter months.

Eye spot often occurs in fields where the soil is very fertile and where weather conditions favor the disease. As may be observed in the illustration, eye spot started to increase during November and the first part of December, while after December 7, 1926, the disease increased much more rapidly, and a peak was reached on March 1, 1927. A second peak was established on March 29, 1927, while still a third peak was recorded on May 24, 1927. After May 24, 1927, the disease decreased very quickly, as shown by the curves. On March 1, 1927, or at the first eye spot peak, the plots receiving nitrogen had 43.18 per cent more eye spot than the plots receiving no nitrogen.

The vertical growth columns and eye spot curves show that there was a decrease in growth correlated with an increase in the degree of eye spot infection. This correlation has been evident in all eye spot experiments where growth measurements and eye spot counts have been recorded. Apparently weather con-

ditions that are most unfavorable for cane growth are most favorable for the increase of eye spot disease.

The applications of nitrogen that were made on March 1, April 1, and May 1, 1927, had little effect on the amount of eye spot that occurred in the various treated plots, as may be readily observed by referring to the illustration; all curves representing the various treatments show a very small difference after March 15, 1927, to the end of the experiment. Since this field was so fertile, as shown in the illustration by comparing the growth of the no-nitrogen-treated plots versus those plots receiving nitrogen after the first six weeks of the experiment, the extra amounts of nitrogen fertilizer applied in the early spring months had little or no effect on the severity of the disease. The eye spot disease rapidly decreased after March 29, 1927, at nearly the same rate that it increased from November 9, 1926, to March 29, 1927.

Summary

1. In the field in which this experiment was conducted, plots receiving an extra application of nitrogen in the fall months did not give a marked response in cane growth as compared to cane receiving no nitrogen.
2. The added amount of nitrogen fertilizer in the fall months increased eye spot infection.
3. The decrease of cane growth during the winter months was coincident with an increase of eye spot infections.
4. All late planting of cane in eye spot areas should be avoided during the fall months, and this in turn automatically eliminates the necessity of any late application of nitrogen fertilizers.
5. Applications of nitrogen fertilizers in March, April and May, did not result in seriously increasing eye spot infections in this experiment.

The Possible Influence of Zinc and Phosphates in Giving Resistance to Eye Spot in H 109 Cane

By F. E. Hance and G. R. Stewart

In February, 1927, George Chalmers, Jr., manager of Waimanalo Sugar Company, requested that we try to find whether there were definite differences in the composition of the soils or of the cane growing in eye spot susceptible fields, contrasted to the soil and cane composition in areas where eye spot did not occur. At Waimanalo, eye spot has invariably appeared in certain portions of the upper fields where the land has been in cultivation for about fifty years. On the lowland areas where cane has been grown for a shorter period, eye spot infection has never been a problem.

Recent investigations by Brenchley (1), McHargue (5), Sommer (6), and others, have shown that minute amounts of a number of the rarer elements are essential for many common plants. We have no definite information as to the

nutritional requirements of sugar cane for any of these less essential materials. It is, however, quite probable that the sugar cane plant has an actual need for some of the less usual plant nutrients.

It therefore appeared to us to be desirable to investigate the composition of the H 109 cane at Waimanalo, both in regard to the usual plant food constituents and the rarer mineral elements. We have obtained some evidence in pot studies that traces of arsenic and copper have apparently acted as stimulants in promoting increased growth.

Experimental Data

Samples of cane plants and soil were collected from the following representative areas:

No. 1—Field 18. Bad eye spot area.
No. 2—Field 18. Area of slight eye spot infection.
No. 3—Field 17. Badly infected area.
No. 4—Field 17. Area of slight eye spot infection.
No. 5—Field 11. Severe eye spot infection.
No. 6—Field 2. Good cane—no eye spot.

Determinations of the available, reserve and total nutrients were made on the above soil samples. The cane was examined for iron and aluminum injury and a spectroscopic examination of the cane ash was made for the detection of the rarer elements. The analytical data appear in the following table:

DATA OF WAIMANALO EYE SPOT INVESTIGATIONS

			Examination of Soils								Examination of Cane Plants	
Field	Condition of cane	pH	Total P_2O_5	HCl Reserve P_2O_5	Citric Avail. P_2O_5	Total K_2O	Available K_2O	Maximum H_2O holding capacity	Hygro. Coef.	Fe and Al Injury	Spectroscopic analyses
18	poor	6.25	.188	.087	.0017	.304	.039	89.5	22.5	None	No zinc
18	good	7.84	.295	.147	.0028	.446	.057	79.3	20.8	"	Zinz present
17	poor	5.81	.305	.170	.0015	.281	.069	75.8	21.2	"	No zinc
17	good	7.22	.303	.138	.0021	.320	.080	78.1	21.7	"	Zinc present
11	poor	6.88	.290	.158	.0012	.368	.059	84.4	22.8	"	No zinc
2	good	7.54	.380	.217	.0664	.502	.111	72.1	19.6	"	Zinz present

For the spectroscopic analyses the stalks and leaves of the cane were ashed separately at a low temperature. The residue was taken to dryness several times with hydrofluoric acid and the material remaining was dissolved in dilute (6 normal) hydrochloric acid. The spectroscope revealed very small traces of zinc in the leaves of the cane which offered the greatest resistance to eye spot disease The cane which suffered from the greatest infection gave no evidence whatsoever of the presence of zinc. The cane from the lowland area gave the most positive test for traces of zinc. By itself this spectroscopic data would be of little value without a long series of equally positive determinations, but we have additional evidence of the influence of zinc in other eye spot studies. In a cooperative investigation carried on with H. Atherton Lee, of the department of pathology, at this Station, we undertook to grow H 109 cane in the presence of traces of various

uncommon inorganic compounds. Among the materials employed, zinc oxide (5 grams in 30 kilos soil) constituted one series of six repetitions.

When the plants in the entire experiment reached the age of four months they were placed in a humidity house and were sprayed with an infusion of eye spot spores. This work was handled by the pathology department under Mr. Lee's direction. After ten days' exposure to the spores in the humid atmosphere the plants were removed and Mr. Lee's staff made a quantitative count of the lesions resulting from the development of the disease.

In the series of treatments it appeared somewhat significant that the cane which had been grown in a zinc environment appeared fourth on the list of eleven so arranged as to show decreasingly progressive resistance to the disease.

In connection with the value of zinc in plant economy, Brenchley (1), of the Rothamsted Experimental Station, states: ". . . zinc is regarded as a catalytic element, as essential to the well-being of the plant as are the more obvious nutrients, carbon, sulphur, phosphorus, etc., in spite of the minute traces in which it occurs."

Traces of zinc are regarded as essential by Maze (4) and Javillier (3).

Ehrenberg (2) concludes that zinc leads to increased growth in plants by an indirect action in the soil.

In order to obtain additional information on the effect of zinc, Mr. Chalmers has reserved a portion of one of his fields in which eye spot appears every year. T. K. Beveridge, agriculturist at Waimanalo, has laid out a series of plots and check plots in the reserved area. He has made one application of zinc oxide in the plots to the surface soil along the rows of a second ratoon H 109 cane. Additional applications will be made so that a total of about twenty pounds of zinc oxide per acre will be applied.

Any effect from the zinc will be observed during the next two seasons at the height of development of the eye spot disease. Royden Bryan, of this Station, has kindly agreed to make quantitative lesion counts on both the check and zinc-treated plots.

The analyses of the soil from the good and poor areas indicate that where the available nutrients are in higher concentration, the cane passed through the season with less infection. This is particularly true in regard to phosphoric acid. The soil, even in the mauka areas, which supported resistant cane, was invariably richer in available P_2O_5 than that near by on which the cane was badly infected. In the sample from the lowland area where eye spot never appears, the available P_2O_5 was quite high.

Increased phosphate applications have been made to the eye spot areas at Waimanalo. The effect of this treatment on the resistance of the cane is being followed with interest.

Summary

The foregoing observations are only offered as a tentative progress report. The spectroscopic determinations which show the presence of minute traces of zinc in the eye spot resistant cane, combined with the results of the pot tests, which showed increased eye spot resistance, in the cultures where small zinc

applications were made to the soil, would suggest that the presence of minute amounts of zinc may make the cane plant less susceptible to the fungus.

The soils of the areas which are free from eye spot on this one plantation appear to be better supplied with available phosphates than the soils of the eye spot fields. There is therefore a second possibility that a better balance of plant nutrients and particularly of phosphates may aid in giving the cane eye spot resistance.

The field trials which are at present under way at Waimanalo should throw some light on the relative influence of these two factors which our experiments show may affect the cane in the good and poor areas. We shall not attempt to draw any definite conclusions on the basis of our present work until it is supplemented by further data on treated and untreated plots in the field.

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The Effect of Covering on the Germination of Sugar Cane Fuzz

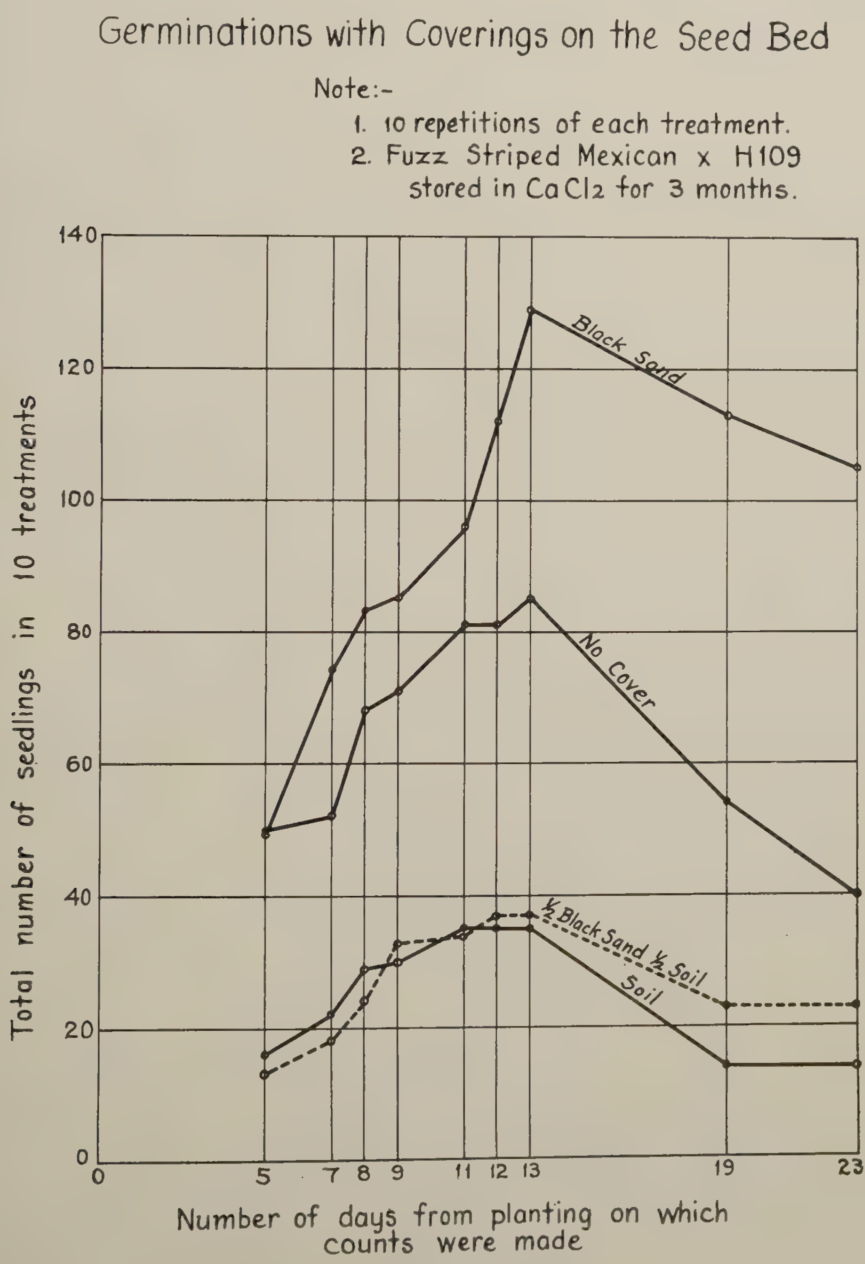
By C. G. Lennox

During the 1926-1927 seedling season a number of studies were made in an attempt to further improve the technique of seedling germination. The use of bottom heat was found very advantageous in promoting quicker and greater germination. Sunlight is shown by Das (1) to be conducive to germination and as much as possible should be given. The use of uspulun on the fuzz flat is still questionable, but it was found very effective by Das (2) in preventing damping off in seedlings newly transplanted from the germinating plot. Sprinkling the young seedlings with a weak solution of ammonium sulfate stimulated growth. The use of a weak, full nutrient solution was reported by Davis (3) as very beneficial in aiding germination and growth. The practice of keeping the fuzz flats covered with thin oil paper until germinations appeared was followed. In efforts to find some other suitable covering medium, sifted volcanic ash was tried with good results.

In the first investigations on covering mediums, Striped Mexican fuzz was used. This fuzz had been stored for three months over calcium chloride. Twenty

flats of the same size were planted to this fuzz. Each flat was then divided in half, each half receiving a different treatment. Ten halves received no covering, ten received a covering of black sand (volcanic ash) sifted through a "tenth-inch mesh" wire screen, ten received a finely sifted soil covering, and ten received a covering of the mixture of half black sand and half soil. The flats were then placed on an outside hot table and given uniform conditions.

The accompanying illustration shows the relative values of the treatments. The coverings of soil and of mixtures of soil and black sand were very deleterious



to germination. The following table, showing the percentage gain by use of black sand against no covering, is interesting:

	% gain of black sand covering over no cover at peak of germination	% gain of black sand covering over no cover at "pricking out" time
Black sand (volcanic ash)	52	160

These figures show that black sand has prevented a large percentage of those germinated from dying off. The mortality rate in black sand was only 18.6 per cent, while with no covering it was 53 per cent.

The results of these figures seemed so positive that further trials were made with the use of black sand and no covering. In these, fuzz from three different varieties was used. Ten flats of each fuzz variety were planted and one-half of each flat was covered with black sand, the other left uncovered. The positive results are again illustrated in the following table:

Variety of fuzz	Total area in sq. ft.		No. germinations fourteenth day		No. per unit area fourteenth day		% Gain by use of cover
	Cover	No cover	Cover	No cover	Cover	No cover	
H 146 x Badila	6.6	6.94	487.0	439.0	73.8	63.4	14.2
H 109 x H 456	6.61	6.99	42.0	30.0	6.35	4.3	48.0
20 S 16 self	6.81	6.78	83.0	59.0	12.2	8.7	40.0

As in the first experiment the mortality rate was greatly diminished by the use of black sand. The following table will illustrate this:

Variety of fuzz	No. per unit area at peak		No. per unit area at last count		% mortality	
	Cover	No cover	Cover	No cover	Cover	No cover
H 146 x Badila	73.8	67.0	69.7	55.4	5.5	17.3
H 109 x H 456	6.35	4.3	5.0	3.0	21.2	30.2
20 S 16 self	16.5	13.7	7.5	5.2	54.5	62.0

A third series of experiments was run in which white coral sand was used. The results as shown in the following table are not sufficiently consistent to warrant its substitution for black volcanic ash:

Variety of fuzz	Black sand vs. No cover			White coral sand vs. No cover		
	Cover	No cover	% Gain	Cover	No cover	% Gain
H 109 x 20 S 16	41	31	32	27	25	8
H 146 x Badila	165	94	75	111	130	14—loss
H 109 x H 27	12	8	50	15	13	15

In the above experiment white coral sand covering seemed to foster the growth of green algae regardless of uspulun treatments.

The beneficial functions performed by a covering of black sand seem to be twofold. First, the covering is of a sufficiently fine texture to keep a continuous film of moisture about the seeds and yet is sufficiently coarse to allow perfect aeration about the germinating seed. It also carries the moisture film high enough above the fuzz bed to feed those seedlings germinating on the top of the bed. Secondly, the black sand seems to prevent the growth of green algae. No trouble

with damping off was experienced in the use of the black sand. Furthermore the newly germinated seedlings may be more easily seen when a black sand covering is used.

SUMMARY

A covering of black sand (volcanic ash) sifted through a tenth-inch mesh wire screen and sprinkled over the fuzz bed in sufficient quantity to just cover the fuzz proved a satisfactory covering material. Covering the fuzz flats in this manner increases the percentage of germination, reduces the rate of mortality in the seedlings, keeps down the growth of green algae and forms a background against which the young green seedlings can be easily seen.

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Additional Inoculation Tests With Sugar Cane Stem Galls

BY H. ATHERTON LEE

The following is a report of further experiments to determine whether stem galls of the Uba hybrids are transmissible by direct inoculation.

The inoculations were made on the variety U. D. 1 at the Manoa substation; the cane had been fertilized with nitrate of soda about a month previously to put it in good, actively growing condition.

The inoculum for the controls consisted of fresh, young, actively growing cane tissues taken from the young top soft joints of normal U. D. 1 cane, and macerated with water in a mortar.

The inoculum for the inoculations consisted of newly formed, fresh, soft, actively growing stem galls from the tops of the U. D. 1 cane at the Mid-Pacific Institute substation. Such young galls in the first series of inoculations (21 to 40) were macerated with water in a mortar. In the second series (41 to 62) the young galls were macerated under a bland oil, Nujol, for the purpose of excluding oxygen which might injure a possible causal agent in the gall tissues.

Inoculations were made by splitting longitudinally through the leaf sheaths, with a knife or thumb nails, and exposing the youngest joints of the cane top; the inoculum was then placed in the tissues of such soft joints, by means of needle punctures. The actively growing meristematic tissue just above the node was selected as the point for the inoculation in this series of inoculations. The leaf sheaths were then drawn together over the point of inoculation, moist cotton placed over the split leaf sheaths, to add to the natural atmospheric moisture and

promote tissue growth, and the top of the cane stalk then wrapped in paraffin paper, and then in opaque paper to exclude sunlight.

These inoculations were made on June 6, 1927, and allowed to continue 86 days before examination, on August 31, an ample period for galls to develop. The inoculation data and results are tabulated as follows:

Stalk No.	Inoculum	Method	Result
1	Healthy tissue	Crushed	Neg.
2	do	in	Neg.
3	do	Water	Neg.
4	do	do	Neg.
5	do	do	Neg.
6	do	do	Neg.
7	do	do	Neg.
8	do	do	Neg.
9	do	do	Neg.
10	do	do	Neg.
11	do	do	Neg.
12	do	do	Rind slightly ridged near puncture
13	do	do	Neg.
14	do	do	Neg.
15	do	do	Neg.
16	do	do	Neg.
17	do	do	Neg.
18	do	do	Lost
19	do	do	Neg.
20	do	do	Neg.
21	Stem Galls	Macerated	Neg.
22	do	with water in	Lost.
23	do	mortar	Lost
24	do	do	Neg.
25	do	do	Neg.
26	do	do	Neg.
27	do	do	Neg.
28	do	do	Neg.
29	do	do	Neg.
30	do	do	Neg.
31	do	do	Lost
32	do	do	Neg.
33	do	do	Neg.
34	do	do	Neg.
35	do	do	Neg.
36	do	do	Neg.
37	do	do	Lost
38	do	do	Neg.
39	do	do	Neg.
40	do	do	Lost
41	Stem Galls	Crushed	Neg.
42	do	under bland	Neg.
43	do	oil (Nujol)	Lost
44	do	in mortar	Neg.
45	do	do	Neg.
46	do	do	Neg.
47	do	do	Neg.

48	do	do	Neg.
49	do	do	Neg.
50	do	do	Lost
51	do	do	Neg.
52	do	do	Neg.
53	do	do	Neg.
54	do	do	Neg.
55	do	do	Neg.
56	do	do	Neg.
57	do	do	Neg.
58	do	do	Neg.
59	do	do	Neg.
60	do	do	Neg.
61	do	do	Lost
62	do	do	Neg.

Seven inoculated stalks were observed with negative results, but labels were weathered or lost.

Conclusions

It would seem from the results of the foregoing inoculations, together with the results of previous inoculations that the conclusion is safe, that stem galls are not readily transmissible by direct contact.

It is still possible, but not probable, that stem galls are infectious, but depend upon insect vectors for transmission.

From the results of the inoculations with organic solutions such as ammonia, ethyl alcohol, etc., the most promising lead now seems to be a study of insects as direct inciting agents of these stem galls, through the injection of such chemicals into the soft actively growing cane tissues.

The Topping of Cane at Harvest

By J. D. Bond

At what point should cane be topped at harvest? Should it be at the growing point, or should the very soft stalk at the top be discarded, and if so, how much? Some have claimed that the discarding of the soft stalk at the top has not only shown better juices at the crusher, but an increased yield in sugar per acre. Others have claimed a loss for this procedure.

To answer this question under local conditions, the Ewa Plantation Company instituted a series of five tests during the crop of 1927 as below:

Test	Field	Date
1	2 A	January 21, 1927
2	23 C	February 10
3	23 B	June 3
4	23 B	June 7
5	A	July 29

In order to place these tests on a practical basis, it was decided to define the lower limit in topping as the removal of one seed piece of three eyes, with the top. This procedure was designated as "topping low." The upper limit was defined as the removal of the top slightly below the growing point so as not to remove any stalk, and so that the cross-section would show fibrovascular matter and no leaf spindle. This was defined as "topping high."

In all tests, plots topped low alternated with plots topped high, there being four or five repetitions of each treatment. Plots were taken of such size as to make a fair load for a cane car—say three or four tons of cane. Tests were all located, laid out and plot divisions cut on the day previous to burning. After burning, one set of men cut all the topped high plots; another set cut all the topped low plots, gathered all the tops and carried these out of the field. Here the tops were re-cut to remove the seed piece and to check with the practice in the plots topped high. This cane was bagged, weighed and crushed in our "Cuba A" sample mill to obtain a sample of juice for analysis. Areas were obtained by measuring the length of all lines in each plot and by assuming exactly five-foot spacing of lines. The weights of cane and samples of crusher juices were obtained at the mill.

The cooperation of the harvesting staff was largely responsible for the success of these tests.

Table I summarizes the results of crusher juice analyses.

TABLE I

CRUSHER JUICE DATA—ARITHMETICAL AVERAGES

Tests			Plots Topped High				Plots Topped Low				Gain for Plots Topped Low	
No.	Field	Date	Brix	Pol'n	Purity	Q. R.	Brix	Pol'n	Purity	Q. R.	Pur.	Q. R.
1	2 A	Jan. 21	15.64	12.98	82.99	10.79	16.32	13.76	84.31	10.05	1.32	0.74
2	23 C	Feb. 10	18.35	16.30	88.83	8.19	18.68	16.68	89.29	7.95	0.46	0.24
3	23 B	June 3	18.53	16.03	86.51	8.47	18.75	16.40	87.47	8.20	0.96	0.27
4	23 B	June 7	19.43	17.28	88.93	7.69	19.33	17.17	88.83	7.75	–0.10	–0.06
5	A	July 29	17.88	15.22	85.12	9.03	18.13	15.63	86.21	8.70	1.09	0.33
Averages			17.97	15.56	86.59	8.71	18.24	15.93	87.34	8.46	0.75	0.25

With the exception of Test 4, the results of which were unaccountably inconsistent, crusher juices from the plots topped low showed a well substantiated improvement, both in apparent purity and in quality ratio, varying from 0.46 to 1.32 for purity, and from 0.24 to 0.74 for quality ratio. This fact is particularly significant when remembering that the tests were conducted on a practical field basis.

The seed pieces removed from the tops of the plots topped low showed the following data:

TABLE II

TOP MATERIAL FROM PLOTS TOPPED LOW—"CUBA A" SAMPLE MILL

Tests: Number	Tests: Field	Brix	Pol'n	Purity	Q. R.	Glucose	Weight, % of Cane as Topped High
1	2 A	8.92	3.70	41.48	195	1.78	4.66
2	23 C	10.53	5.85	55.56	40	......	1.70
3	23 B	9.95	4.35	43.72	116	......	2.82
4	23 B	11.40	5.85	51.32	47	......	3.00
5	A	11.35	5.70	50.22	52	3.30	4.37
Averages		10.43	5.09	48.80	63	......	3.31

The extraction of polarization in our sample mill at the last test was 61 per cent. In all probability, then, if this material were crushed by commercial equipment, the purities would be considerably lower. In all cases, juices were so low in Brix and purity that the quality ratio was not better than the order of 50, reaching a high figure of 195 in Test 1.

The top material from plots topped low was rich in glucose as shown by the ratio $\frac{\text{glucose}}{\text{polarization}}$ x 100. This figure for Test 5 for crusher juice from plots topped low was 6.4 as against 57.9 for the top material as crushed in the sample mill. The influence of this in the crusher juice of the cane from plots topped high was not great, the average for these plots of Test 5 showing 1.07 per cent glucose as against 1.00 per cent for the plots topped low.

There remains the effect of the treatments on the calculated sugar yields. Though juice data were satisfactory, the yields of cane per acre from the various plots showed such a wide fluctuation, that averages do not and indeed cannot be expected to show differences as small as 1.7 per cent to 4.7 per cent. In order to calculate comparable sugar yields, we then assume uniform yields of cane, differing in the plots topped low by the average per cent of material removed by topping low as directly determined by weights. This uniform yield of cane for each test will approximate, in round numbers, the average yields of all the plots in that test. Table III shows these data.

TABLE III

CALCULATED SUGAR YIELDS WITH ASSUMED UNIFORM CANE YIELDS

Tests			Plots Topped High			Plots Topped Low			Gain in Sugar per Ac. for Plots Topped Low
No.	Field	Date	Cane per Ac.	Q. R.	Sugar per Ac.	Cane per Ac.	Q. R.	Sugar per Ac.	
1	2 A	Jan. 21	140.00	10.79	12.97	133.48	10.05	13.28	0.31
2	23 C	Feb. 10	120.00	8.19	14.65	117.96	7.95	14.84	0.19
3	23 B	June 3	130.00	8.47	15.35	126.33	8.20	15.41	0.06
4	23 B	June 7	115.00	7.69	14.95	111.55	7.75	14.39	−0.56
5	A	July 29	100.00	9.02	11.09	95.63	8.70	10.99	−0.10

It is significant that the gain in sugar yields for topping low decreased throughout to a definite loss in the latter part of the crop. This will hold true, though the data of Test 4 be discredited, due to fluctuations, the cause of which is not understood. We may expect, then, that as the cane approaches the peak season, as far as juices are concerned, in April, May and June, topping low becomes, at Ewa, a doubtful, if not uneconomical procedure, but that previous to that time, is fully justified, not only in increased yields of sugar, but also, since contracts are based on the tonnage of cane received at the mill, in the reduction of the costs of cultivating, cutting, loading, transporting and milling, eliminating about 3 per cent of all cane which, as far as sugar manufacture is concerned, is virtually worthless.

SUMMARY

Tests instituted to determine the point at which to top cane at harvest under local conditions have shown that it is profitable to top cane so as to remove one seed piece of three eyes only during the early part of the crop. Presumably, as the peak in juice purities (and in the sucrose content of the cane) is reached, the advantage in topping low becomes progressively less, and at the peak period shows a decided loss.

A Practical Method of Using Molasses as a Fertilizer

BY J. A. VERRET

With the present low market values for molasses a great deal of it is not now marketed. A portion is used as fuel. But many plantations have all the fuel they need from bagasse, so a large part of our molasses is now allowed to run to waste into the sea. A very small portion is run on low fields in irrigation water. A small amount is sold.

With our present crops we produce very nearly 200,000 tons of molasses per year. This molasses contains from about .4 to over 1.5 per cent of nitrogen, .15 per cent to .3 per cent phosphoric acid and from about 2 to 6 per cent of potash.

The total nitrogen, phosphoric acid and potash in our final molasses and their values on the plantations would be approximately:

	Tons	Value
Nitrogen	1,400	\$ 406,000
Phosphoric acid (P_2O_5)	500	50,000
Potash (K_2O)	8,000	720,000
Total		\$1,176,000

This gives our molasses a net value on the plantation of over \$5.00 a ton, without giving a value to the organic matter and lime which it contains.

In Mauritius and in Java, considerable quantities of molasses are used as fertilizer. In Mauritius, molasses is used at the rate of from 4 to 15 tons per acre; some figures we have seen from Java indicate a use of about 10 tons per

acre. It is not considered safe to use undiluted molasses on growing crops, especially in the larger amounts. Molasses in contact with the growing crop can result in serious burn. Also as the molasses ferments and decomposes, denitrification of the soil takes place and plants suffer temporary nitrogen starvation.

Here it may be well to note that the use of molasses in the irrigation water to growing cane should be practiced with caution. We know when molasses is applied to the soil that temporary denitrification takes place. This denitrification is brought about by the cellulose decomposing bacteria. These bacteria absorb the nitrates in the soil and change them into proteins. This organic nitrogen is not lost, but is of no use to the plant until the bacteria die and their protein content is again changed to nitrates. From the above we see that a field could be kept in a continuous state of denitrification by the application of molasses often enough with the irrigation water. All the molasses to be used on a field should be applied in one dose in order to shorten the time of nitrate shortage in the soil. This would indicate that it is bad practice to empty the molasses in a reservoir and use it that way in routine irrigation. The molasses should be put in the level ditches for each field.

The most satisfactory method of using molasses is to apply it to fields about to be plowed in order that the molasses may be in the ground one to two months before planting.

Molasses as such is extremely difficult to handle, and it would not be practical to use it on many of our fields, and very often these are the fields which need it the most.

It would help a great deal if molasses could be made portable. It occurred to some of us that perhaps a mixture of molasses with other mill by-products could be made in such combinations as to allow the mixture to be bagged so that it could be handled in the same way that we now handle press cake and stable manure.

Dr. F. E. Hance, of the chemistry department, and the writer, have been working on the problem. Dr. Hance has been working more with special mixtures for use in poor areas of fields in connection with his "replaceable base" work. Dr. Hance will report on this as the work advances.

We will discuss here work having to do with what might be called the "routine mix" for general use.

The basic idea is to take molasses, press cake and mill ashes in the proportion in which they are turned out by the factory, and adding to this enough bagasse to make a mixture which can be bagged and spread on the field from the bags or by means of a manure spreader. In this way all the molasses, press cake and mill ashes would be used in addition to a small amount of bagasse, about 3 or 4 per cent.

From the Synopsis of Mill Data we find that the final molasses amounts to 3 per cent of the cane and press cake to about 2¼ per cent. We have no data as regards the amount of mill ashes produced. We can arrive at an approximate figure by using the ash content of the bagasse. This varies in different districts from about .5 to .9 per cent. As the bagasse amounts to 22.5 per cent of the cane this will give us an average ash of about .15 per cent on cane. There is

some loss in burning, so the actual amount obtained would be less than indicated above, about 1 pound of ash to 20 of molasses.

With the active cooperation of the Waimanalo Sugar Company the actual mixing was then tried. We used a concrete mixer for the purpose. Of course other forms of mixers would lend themselves better to the purpose, but this worked fairly well.

W. W. G. Moir has informed us that at Olaa Sugar Company they found that for mixing large batches, hand mixing was faster than a concrete mixer. Very likely a fertilizer mixer would work very well. Soil and manure mixers may also serve the purpose. The materials are taken directly as they come from the mill except that the press cake is pulverized and the molasses made very hot.

After several trials the following gave very good results:

PROPORTION OF MIX

Mill ashes	24 lbs.	5.5%
Bagasse	53 "	12.2%
Press cake	147.5 "	33.8%
Molasses	209.5 "	48.5%
Total	434 lbs.	100.0%

This material had the following composition:

Nitrogen	0.40%	8 pounds per ton
Phosphoric acid	0.81%	16 " " "
Potash	2.65%	53 " " "
Lime	1.09%	22 " " "

This mixture compares well in fertilizer value with either press cake or stable manure as shown in the following comparison:

	Molasses mixture	Press cake	Stable manure
Nitrogen	0.40%	0.59%	0.50
Phosphoric acid	0.81	0.61	0.25
Potash	2.65	0.01	0.50
Lime	1.09	0.92	......

The mixture as made amounts to about 7 or 8 per cent on cane. With a yield of 60 tons of cane per acre this would give about 4.5 tons of this fertilizer per acre or 36 pounds of nitrogen, 72 pounds of phosphoric acid, 238 pounds of potash and 108 pounds of lime.

We are trying experiments with this, both in pots and in the field, on fields to be plowed and on growing ratoons. We are especially anxious to try this on some of our poorer acid mauka fields where it is not now practical to apply molasses.

The Olaa Sugar Company has done some work along these lines. They found that the following amounts gave a nice material easy to handle:

Molasses	1000 pounds
Press cake	600 "
Mill ashes	100 "
Bagasse	300 "

They have put in large field tests with this material, which had the following composition:

		Pounds per Ton
Nitrogen	0.78	16
Phosphoric acid	1.74	35
Potash	1.48	30
Lime	1.74	35

The Experiment Station is anxious to try this on as many plantations as possible in order to get conclusive evidence as to the value of these mixtures. We would be glad to cooperate in making trial mixes and in putting in field tests.

Molasses as a Fertilizer*

By W. W. G. Moir

The general interest in the utilization of molasses and other sugar by-products as fertilizers has prompted the writer into a discussion of a few of the articles that have been published upon this subject in the past, together with the application of some of the more recent research results to their conclusions.

A short historical sketch of the use of molasses as a fertilizer may be found in Bulletin No. 28 (General Series) of the Department of Agriculture of Mauritius on "The Application of Molasses as a Fertilizer to Cane Soils in Mauritius." The practice originated at about 1860, but did not become general until about 1900 and "is now part and parcel of recognized planting practice in Mauritius."

In Mauritius, molasses is applied either to the land before planting or to the interlines in ratoon areas. Sometimes it is mixed with ash and sugar scums before application. In the slower growing districts it is applied to the interlines even in very small plant cane. But in the plant field it is usually applied several weeks before planting, as molasses applied close to young cane has resulted in killing the young plant. The benefits from this application usually show up first in the plant crop and continue to do so for several crops. The applications are usually from 4 to 15 tons per acre:

> Regarding the benefits to be derived from applications of molasses, it is commonly believed that on a cycle of one crop of virgins and five succeeding crops of ratoons, the gain in yield to be ascribed to applications of molasses amounts in the aggregate to as much as 20 tons per acre.

In Hawaii, we have not yet adopted as a general practice the utilization of this by-product as a fertilizer in our cane fields. Many plantations have run their waste molasses into the sea when there has been no market for it, while others have placed it in the irrigation ditches and continuously irrigated a limited, usually very fertile, area with this water-molasses solution. In spite of these continuous heavy applications of molasses no decrease has been made in fertilizer applications to these fields. From what has been shown in results obtained in Mauritius and

* A paper presented at the Forty-seventh Annual Meeting of the Hawaiian Sugar Planters' Association, Honolulu, November 16-21, 1927.

which are later reviewed in this article, this practice should be an unremunerative one if not detrimental.

We have records of heavy molasses applications to growing cane or stubble causing the death of the plants and still other data showing a marked stimulation in the growth. The texture and moisture content of the soil have much to do with the results obtained. With the open, coarse textured soils found in the majority of fields of Hawaii little harm can be expected even up to a 40-ton per acre application, while on the finer silts and heavy clays complete killing out should be expected from applications of half that amount. A remedy for the latter situation is to irrigate immediately after the application of molasses. Molasses has been applied to the kuakuas (interlines) in newly planted fields at Olaa without detrimental effects, and even on stubble at the rate of 40 tons or more without any killing or checking in growth becoming noticeable. In heavy, poorly drained soil in which molasses has been well plowed in, a checking in the growth has been noted if the application has been made within two or three months before planting. But following a period of two or three months from planting, a stimulation in growth has been noted.

The first systematic experiments to test the manurial effect of molasses on cane were carried out in Java in 1903 and 1904. In some of these the cane was killed, in others there were negative results and in still others increase in yield.

The result of the work of Boname at the Station Agronomique in Mauritius in 1909 may be tabulated as follows:

	Metric Tons Cane		Gain Due
	Molasses	No Molasses	to Molesses
No fertilizer	19.34	18.99	1.65
No nitrogen	29.43	24.27	5.16
No phosphoric acid	27.67	26.26	1.41
No potash	33.60	29.44	4.16
Complete fertilizer	35.05	30.27	4.78

These are averages of four crops from the same area. The molasses used was 5 tons per acre before planting. Mauritius soils are normally low in phosphates and one can easily see how this deficiency has affected the yields. It will also be noted that the plots receiving no nitrogen and no potash are not materially affected because molasses supplies these elements in abundance. If one considers only the returns of the plant crop greater differences will be noted.

	Metric Tons Cane		Gain Due
	Molasses	No Molasses	to Molasses
No fertilizer	28.32	26.28	2.04
No nitrogen	45.84	34.44	11.40
No phosphoric acid	33.60	29.16	4.44
No potash	45.62	33.96	11.66
Complete fertilizer	46.40	36.36	10.04

It will be seen from these figures that on the plant crop 5 tons of molasses added to the complete fertilizer doubled the gain of the complete fertilizer over no fertilizer. This 5 tons of molasses application added 200 pounds of potash and 35 pounds of nitrogen.

The results of the experiments in Java in 1909 are reviewed in the *Hawaiian Planters' Record* of September, 1910, page 130, and also in the Mauritius Bulletin No. 28. Molasses was applied one month before planting and gave increases in yield amounting to 10 tons of cane per acre.

In the Mauritius Bulletin, we find the following gains for two crops of molasses over no molasses on soils equally treated with pen manure and with different fertilizers:

GAIN IN TONS CANE PER ACRE FROM 5 TONS MOLASSES OVER NO MOLASSES.

	Plant	Ratoon	Total
1. Nitrate of soda...............	8.7	6.2	14.9
Guano phosphate			
Sulphate of potash			
2. Nitrate of lime	7.3	0.5	7.8
Guano phosphate			
Sulphate of potash			
3. Nitrate of soda	8.6	12.2	20.8
Nitrate of potash			
Guano phosphate			
4. Sulphate of potash	15.6	14.5	30.1
Guano phosphate			
5. Nitrate of soda	19.0	10.6	29.6
Nitrate of lime			

The biggest gain being obtained where no nitrates were applied.

In a second series of tests in 1920-21 further proof of the benefit of molasses is given:

On the weighted mean of the two series of experiments, the application of 20 tierces of molasses per acre (5 tons) has given rise to an increase of 9.65 tons of cane per acre in virgin cane (plant).

This 5-ton application of molasses has applied about 31 pounds nitrogen, 16½ pounds P_2O_5 and 121 pounds of potash. Their soils are very deficient in phosphates and low in potash, but these amounts added should not account for these gains in cane yield.

In the *Hawaiian Planters' Record* of July, 1927, will be found an abstract of this Bulletin, No. 28, from Mauritius.

At Pioneer Mill Company, molasses has been very satisfactorily applied to areas to be plowed and planted by irrigating the old furrows with a mixture of molasses and water. Varying amounts have been applied on different level ditch size plots and the cane from this experiment will be harvested this coming crop (1928). Observations on the growth of cane on these plots have shown that the cane on the molasses plots has consistently outgrown that on the check plots. The difference between the 40-ton molasses application and the check is extremely more marked than that between the 10-ton and check plots.

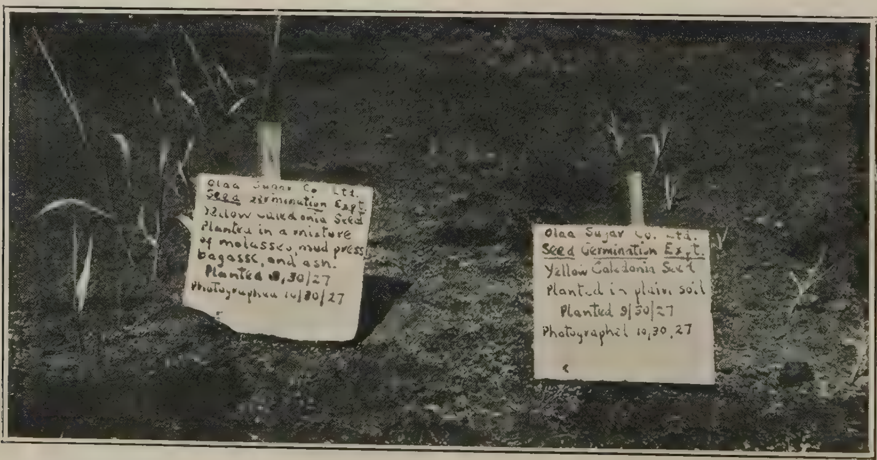
In another area at Pioneer, a part of a field of a few acres in extent was given an extremely heavy application of molasses when it was fallow. A few months later it was plowed and planted. The adjoining section of the field, as well as the

molasses area, had a heavy application of mud press and the whole field a heavy fertilization. No differences were noted in yield between the different parts of this field at harvest, the whole yielding at the rate of 90 tons per acre. The plantation was unable to take care of the ratoons except for an occasional flooding irrigation and one application of fertilizer for four or five months after harvesting in June, 1924, due to the labor strike. The weeds were very heavy in the whole field but the cane on the molasses area continued to grow. The whole field was treated uniformly and at harvesting in 1926 the molasses area yielded as much as the plant crop and twice as much as the adjoining area upon which molasses had not been applied.

In 1922, in an experimental layout at Pioneer Mill Company in a field adjoining the two areas just mentioned, molasses was applied at the rate of 2 tons per acre to plant cane about 1½ to 2 feet high. The molasses was applied by buckets to the sloping side of the kuakua on the upper side of the cane row. Two amounts of nitrogen treatments were also included as variables in this experiment and the results obtained in 1924 are given below:

	T. C. A.	Q. R.	T. S. A.
90# of N. + 2 tons molasses per acre	61.1	6.62	9.24
90# of N.	58.4	6.62	8.83
180# of N. + 2 tons molasses per acre	71.3	6.95	10.25
180# of N.	71.6	7.00	10.23

The molasses analyzed as follows: 0.65 per cent N, 5.44 per cent K_2O and 0.16 per cent P_2O_5. Molasses with the smaller amount of nitrogen gave a gain of .41 ton sugar per acre over the no-molasses. This gain in the low nitrogen plots was very definite in that in all cases the molasses plots were better than the adjoining no-molasses plots (four repetitions of each). With sugar at \$90 a ton a gain of .2 ton of sugar for each ton of molasses added, we would have a gross return for one ton of molasses of \$18. The applying of one or two tons of



A test showing the influence on germination from an application of a mixture of molasses, mudpress, bagasse and ash. The larger shoots on the left were treated, those on the right were untreated. The cane was planted September 30, 1927, and photographed October 30, 1927.

molasses in irrigation water would not amount to more than about $3 per acre. This would still leave a net return for molasses as a fertilizer of about three times the net return for the sale of molasses.

The lack of difference in yield when the molasses and check plots both got 180 pounds of nitrogen and the increase in yield of the molasses plots over the check plots when both got 90 pounds of nitrogen, would make it appear that part of the nitrogen added to the molasses plots in the 180 pounds dose was unremunerative and could have been saved.

Molasses has been very satisfactorily applied at the rates of 9 tons and 18 tons per acre on the unirrigated lands of Lihue before plowing by means of a large tractor-drawn dump wagon with valve gates to regulate the flow of molasses. Tank cars have been emptied into the dump-wagon very rapidly by the use of compressed air. The easiest method of applying molasses seems to be through the irrigation water, and many plantations have been successful in applying large doses without any harmful effects to the standing crop.

From an article in the October, 1927, *International Sugar Journal*, abstracted from the "*Sugar Supplement of Tropical Agriculture*," the following quotation is copied:

> A a fertilizer molasses has found favor in Mauritius and Java. According to certain figures of increased production, the net value realized was 2⅓ cents per gallon, on a conservative basis.

Taking 167 gallons as equal to a ton of our molasses this would represent $3.90 net value of one ton of molasses as a fertilizer. This is much more than the net return for a ton of molasses at the plantation at the present time. It is also a rather low figure in view of the results obtained at Pioneer and the observations on the stimulation of the ratoon crops for several cuttings.

Peck's work on the effect of molasses on ammonification, nitrification and the denitrification of nitrates in lysimeters and in beakers, has long been a point of controversy in the use of molasses in Hawaii. He concluded from his first tests in glass beakers that (Exp. Sta., H. S. P. A., Bulletin No. 34):

> (1) Molasses applied at intervals on land on which cane is growing and fertilizer has been applied will work harm by destroying nitrates already applied or by preventing the formation of nitrates from other sources of nitrogen supplied in the fertilizer. (2) Molasses applied to land lying fallow or at an interval of several weeks prior to the planting of the crop may produce beneficial results by providing a stimulus to the nitrogen fixing bacteria of the soil, and thereby adding a store of nitrogen to the soil in a form which can be made readily available to the crop at a later date by the other organisms in the soil.

In the second series of tests in lysimeters (Exp. Sta., H. S. P. A., Bulletin No. 39):

> The general conclusion is that the results of experiments with soil in small containers, as given in Bulletin No. 34 of this Station, are substantiated.
>
> Molasses applied to land which is receiving the usual fertilizer applications as practiced in these Islands will work harm by causing a part of the nitrogen applied as nitrate to revert back to less available or unavailable forms of nitrogen; by checking the nitrification of sulphate of ammonia dressings; and by retarding the ammonification and nitrification of the nitrogen of organic fertilizers.
>
> The harmful effect of molasses dressings is due entirely to the organic constituents of the molasses, the mineral matters having no influence.
>
> Dressings with carbonate of calcium do not correct such adverse action of molasses.

These lysimeter tanks, studied for only five months, had no crop growing upon them, and, therefore, are not comparable to field conditions. It would be well worth anyone's time to read over this bulletin and study the tables of figures given as well as the conclusions drawn. The maximum amount of molasses used was but two and a half tons of molasses per acre. It is certainly remarkable that this small amount of molasses was so efficient in tying up a large part of the nitrogen and preventing the leaching of it into the drainage water. This represents an application of plant food of 13 pounds of nitrogen, 8.6 pounds phosphoric acid, and 272.6 pounds of potash per acre. The molasses was applied two weeks before the first irrigation in the series of lysimeters, receiving one application of 400 gallons per acre, while in the other series molasses at the rate of 40 gallons per acre was applied at each irrigation. The different forms of nitrogen at the rate of 100 pounds per acre were applied one week before the first irrigation, and the lime carbonate two weeks before.

From our present knowledge of the effect of molasses and lime, we can be reasonably certain that these were not applied long enough before starting, nor were the tests carried on long enough. If the irrigations applied to these tanks represent normal field applications every two weeks, and the amounts of nitric nitrogen secured in the drainage in these tanks represent field conditions, we certainly should be thankful that as small an application of molasses as used in these tests should be able to conserve this outflow of valuable nitrates to as much as 15 per cent during a five-month period.

Does this not suggest the use of molasses in irrigation water during the fall and winter months so that the normal rains will not leach out nitrates and still have them become available at a later date? And does this not suggest the possibility of applying most of the nitrogen to your fields in the first few months of growing and then by irrigating with molasses water for a short period, both to conserve the nitrogen, and to prolong the good effects of early stimulation of growth? This would create a natural storehouse of nitrogen in the soil upon which the plant would draw instead of waiting for a "shot" of nitrogen.

There are several points of interest in these tables of Peck's, a few of them being the increased amount of mineral matter in the drainage from tanks treated with fertilizers, and especially sulphate of ammonia; the increased amount of chlorine, lime and magnesia in the drainage in molasses treated soils; the increased alkalinity in molasses treated soils; and the very small amount of potash in the drainage due to the application of molasses. These tables are well worth a closer study than my time and space here permit.

In the *International Sugar Journal* for August, 1927, will be found an abridged printing of another bulletin published by the Mauritius Department of Agriculture on "The Reversion of Nitrates in the Soil under Cultural Conditions in Mauritius." The results of experiments conducted there

"have shown that when artificial nitrogenous fertilizers are applied to cane lands, which have already received dressings of organic manure and molasses, little or no effect is frequently observed. . . . In Mauritius the application of artificial nitrogenous manures is widely practiced, and the net result of these investigations is to show that a considerable part of the artificial manures so applied may very probably be unremunerative. This result is

of profound importance to the sugar industry and should receive the most careful attention of all planters.

The conclusions drawn are:

(a) Under the conditions in which this investigation was carried out, the application of large amounts of molasses caused nitrification to be arrested, and causes ammonium compounds to become converted into organic nitrogenous compounds.

(b) Nitrates which are present in the soil are, on the addition of large amounts of organic matter to the soil, reverted to less readily available forms. Molasses causes the greatest loss in nitric nitrogen, dried green manure and dried farmyard manure following in the order named.

(c) Molasses and dried green manure do not seem to cause any increase in the loss of nitrogen in the gaseous form, whereas with farmyard manure a big increase in this loss occurs.

The results reported by this Mauritius Bulletin were obtained from a study of small quantities of soil, approximately 4½ pounds in each treatment, placed in glass jars with 250 c. c. of water, and treated with various materials. The figures were obtained for the various forms of nitrogen at the start and again at the end of the experiment ten months later. The gain (+) or loss (—) in grams during the ten-month period are given below:

	Ammoniacal	Nitric	Organic	Total
Soil	+0.021 grs.	+0.007 grs.	+0.038 grs.	+0.066 grs.
Soil + Molasses	+0.043	—0.007	+0.065	+0.101
Soil + Sulphate of Ammonia.	—0.753	+0.695	+0.111	+0.053
Soil + Sulphate of Ammonia + Molasses	—0.646	+0.191	+0.450	—0.005
Soil + Nitrate of Soda......	+0.014	—0.189	+0.215	+0.040
Soil + Nitrate of Soda + Molasses	+0.102	—1.148	+0.996	—0.050

It should be noted from the figures above that the molasses alone has increased the total nitrogen in the soil more than any other treatment; that the soda and ammonia have added to the total nitrogen of the soil less than the soil alone, and that when molasses was combined with these nitrogen fertilizers there was an actual loss of nitrogen which was much more marked in the soda treatment.

It certainly appears from the reading of this bulletin that but a single jar was used for each experiment, with none of the experiments repeated. In the second series of experiments two jars were similarly treated as the two in the first series, and below is given the grams gained or lost, to show what large differences were obtained in the two cases.

	Ammoniacal	Nitrogen Nitric	Organic	Total
Series 1 #5 (10 months) Soil + Soda..	+0.014	—0.189	+0.215	+0.040
Series 2 #1A (10 months) Soil + Soda.	+0.067	—0.092	—0.250	—0.275
Series 2 #1B (14 months) Soil + Soda.	+0.057	—0.025	—0.546	—0.514
Series 1 #6 (10 months) Soil + Soda + Molasses.........................	+0.102	—1.148	+0.996	—0.050
Series 2 #2A (10 months) Soil + Soda + Molasses......................	+0.278	—0.984	+0.365	—0.341
Series 2 #2B (14 months) Soil + Soda + Molasses	+0.301	—0.989	+0.366	—0.322

In all these experiments 2 kilograms of soil, 250 c. c. of water and 7.5 grams of nitrate of soda were used, while in the ones treated with molasses 60 grams were added. One thing these figures show clearly is the greater and quicker loss of total nitrogen in the soils treated with soda alone than in those that had molasses in addition to the soda. This undoubtedly is one of the reasons why molasses applied to the fields has had such a lasting stimulation. It will also be noted from these figures that the organic nitrogen is being stored in greater quantities for future use where molasses has been applied.

In the general discussion of results it is mentioned that in the mixture of molasses with either green manure or farmyard manure there is less loss of nitric nitrogen—molasses alone caused 72.9 per cent to revert; molasses and green manure 53.8 per cent; and molasses and farmyard manure 63 per cent.

According to Doryland, addition of a small percentage of sugar lowers the ammonification and, therefore, of necessity, lowers nitrification. In this case it seems that the bacteria of the soil have first of all derived the energy necessary for their existence by means of oxidizing the readily available organic material, i. e., the molasses. When this source of energy is completely finished the bacteria may derive their energy from the ammonia or nitrates already existing in the soil. According to Thornton, when a nitrogenous source of energy predominates, ammonia is released; but when a non-nitrogenous source predominates, it may be assimilated. In the experiments under discussion it is seen that when a large quantity of molasses is added to the soil, it has the effect of causing the disappearance of large amounts of nitrates.

Mauritius soils are high in organic matter, and every attempt is made to return cane trash and pen manure to the fields as well as molasses. Although nitrogenous fertilizers are added later, there is practically no response to them. In considering these results one must realize that there may be more than one way of loss by denitrification.

First of all it consists of the process whereby nitric nitrogen is converted into organic nitrogen, i. e., the reverse of nitrification; secondly, it also comprises the process in which nitric nitrogen is set free to the atmosphere as gaseous nitrogen, i. e., the reverse of nitrogen fixation. Thus it is quite possible that although the denitrification caused by two different manures may be the same in quantity, yet the final products may be vastly different. Addition of molasses or a dried green dressing does not seem to have increased the loss in total nitrogen; it would seem, therefore, that the action of these manures is to bring about a reversion of nitric nitrogen to an organic form, not to set it free as gaseous nitrogen. This may be an important point in the conservation of the soil nitrogen, as nitrogen reverted to the organic form is not lost, but merely rendered unavailable for a certain length of time, whereas a total loss occurs when gaseous nitrogen is evolved.

This is very important and should be kept in mind in reviewing the work done by investigators who have claimed that molasses was detrimental when applied to the soil. If nitrogen is stored as organic nitrogen in the soil due to the addition of molasses, we have a ready supply upon which the plant can draw at a later date. Even if nitrogenous fertilizers are applied to this same soil sometime after a molasses application, we can be fairly sure that the excess will not be leached from the soil, but stored for future use by the plant. Is this not a better practice to follow, where the plant gets its nitrogen from a natural storehouse than where it gets it through a scheme by which man flatters himself that he knows when the plant will require it?

It is unfortunate that such detailed work as that carried on by these Mauritius investigators, and by Peck in Hawaii, should not have included several repetitions of each treatment and also have included actual field study with crops growing upon the several treatments. If we were to entirely accept the results obtained through these experiments, we should conclude that molasses caused a loss of nitrates in the soil during a certain period after application, and that it was detrimental and should not be used. But from observations and experimental data we know that molasses gives a stimulation to growth with increased yield, and that this stimulation is very often noticed within a very short period after application to the standing crop. Therefore, there must be a difference in conditions between soils in jars and soil in the field to account for these different results.

In the several articles on work done in Mauritius and at Rothamsted, it has been pointed out that the molasses should be applied sometime before the planting of a crop. During this period the denitrification processes will probably be completed. Nitrification has been arrested mainly due to the conversion of all the ammonia into organic nitrogen. After a certain period of time ammonifying and nitrifying bacteria are stimulated into greater activity and render the stored organic nitrogen into nitrates for the use of the plant. Besides this rendering of the nitrogen available by these bacterial activities, there is a liberation of plant foods from unavailable reserves and an improvement of physical conditions in the soil. Nitrogen fixing bacteria are greatly stimulated by the addition of molasses or such easily oxidizable carbohydrates which they use as energy to complete their life processes. If the soil is rich in nitrates they will utilize these nitrates instead of taking nitrogen from the air, thus becoming harmful instead of beneficial. This is probably what becomes of nitrates when applied to areas recently treated with molasses, or when molasses is applied in every irrigation made to a field that has had heavy nitrate applications.

Many factors, such as texture of soil, organic content, and microbiological activity, control the length of this period of denitrification, but from an observation of conditions in Hawaii it would appear to be very short.

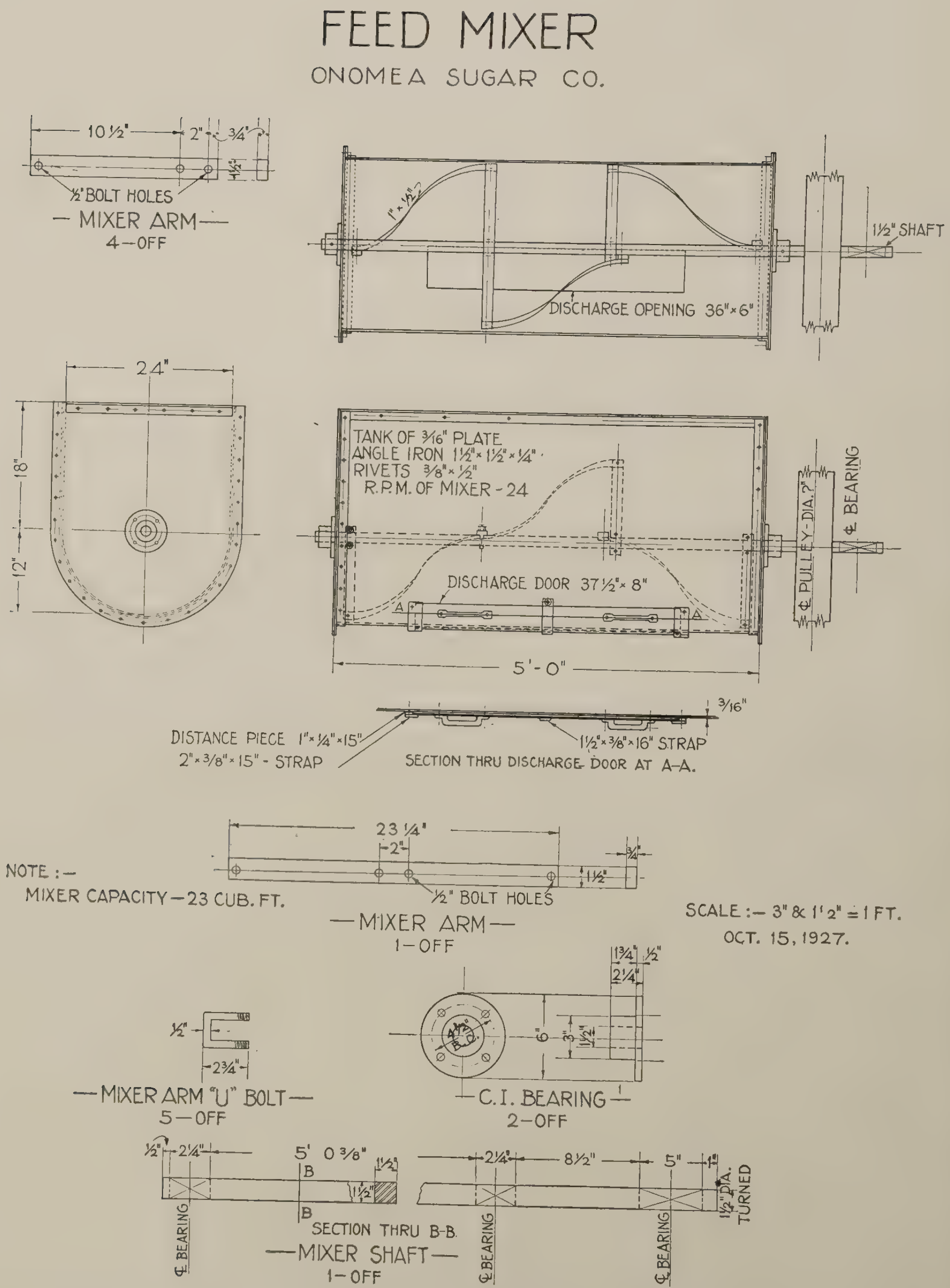
In the *Hawaiian Planters' Record* of June, 1911, was reprinted the results of an interesting test in South Africa which is repeated here:

TONS PER ACRE (CANE)

	Plant	Ratoon	Total
1. Complete fertilizer 50#N—70#P_2O_5—50#K_2O per acre.	34.1	28.3	62.4
2. Same + 600 gals. molasses per acre (3.6 tons)	42.5	31.6	74.1
3. 400 gals. molasses (2.4 tons), 1 ton press cake, ½ ton bagasse ash	40.2	33.8	74.0
4. Nothing	24.6	17.2	41.8

It will be noted that treatment 3, utilizing only by-products of the industry, gave about the best results.

This brings up the subject of a mixture of by-products or the application of any one of them to our fields in place of the purchase of commercial fertilizers. This is at the present time of great interest to many plantations and much experimentation is going on. Next year at this time we should have some very inter-



A feed mixer which offers possibilities of usefulness in preparing a mixture of the by-products: molasses, mudpress, bagasse and furnace ash.

esting data to present on this subject. Much to the surprise of many people a mixture suggested by members of the Experiment Station staff utilizing molasses, mudpress and mill ashes, in proportion as they are produced each day at the factory, plus an amount of bagasse, less than 3 per cent of the daily output, will make a mixture finer in texture and as easily handled as farmyard manure. Experiments on amounts to apply per acre on ratoons and plant are under way at present. Preliminary observations of some of these tests show that seed planted in this mixture in the bottom of the furrow without mixing it with the soil, but covering over the whole with soil, has germinated a week sooner than seed planted in ordinary soil. The week earlier germination has resulted in greater growth to date. Applications of this mixture at rates of 20 and 40 tons per acre immediately on the stubble after mixing have not only acted as a mulch in keeping down weeds, but has stimulated the ratoons into greater stooling of a greener color than where no mixture was applied. There is a generation of heat in the mixture a short time after mixing, which helps considerably in stimulating growth. The analysis of this material is quite variable depending upon the amounts of each material used and the plantation considered.

The addition of phosphates or potash to bring up the amounts per acre in very deficient areas should be easily accomplished. Here we have a natural by-product fertilizer which should cost very little per ton to mix on the plantation, and which will more than likely replace all of the fertilizer now applied to many of our poor upland fields as well as supplement or replace much of the fertilizer on the better lands.

From the many profitable returns from molasses applied to land in other countries for a good number of years and from the many indications of its value here in Hawaii during the last few years, it seems like a tremendous waste of a profitable by-product not to apply it to our lands. This latest mixture mentioned above offers a simple means of returning to our land the greater part of what the crop removed from it while growing. Many minute amounts of certain elements necessary to good growth and about which we know very little will also be returned, insuring continued fertility.

We can, therefore, conclude from this discussion that:

(1) Molasses as a fertilizer is extremely beneficial to yields, the stimulation lasting over several crops.

(2) A certain period of time should elapse between the time of heavy applications to certain soils and time of planting.

(3) Lighter applications can be made with safety to growing canes through irrigation water, and on the interlines when applied without dilution.

(4) In unirrigated areas heavier doses may be applied to the interlines with safety even on newly planted areas.

(5) A mixture of by-products—molasses, mudpress, bagasse and ash—will be even more beneficial and probably a more economical method of applying molasses.

(6) Better results are obtained from molasses when nitrate fertilizers are left off or only light applications are made.

What the gain from these applications of by-products may be due to is still an open question, but that we get the increased returns is beyond a doubt. Whether the molasses causes a partial sterilization of the soil and a later stimulation of nitrification, whether the nitrogen-fixing bacteria are greatly stimulated, or plant foods are made more available, or nitrogen stored for use over a longer period of time, or the soil solution and soil in general made more alkaline, remains to be proven.

One of the things that was most outstanding to me at the recent Washington meeting of the Soil Congress was the great amount of interest taken in the subject of Organic Matter and Microbiology of the Soil. Since this matter I have been discussing is on this very subject, and so little has been done in Hawaii on the study of these operations in the soil, and since by the slightest improvement of conditions for greater microbiological activity we can have a vast army working for us without wages, I feel that it should be strongly recommended to the Trustees of the Hawaiian Sugar Planters' Association that a department of microbiology be created at the Experiment Station to study these matters, and that a trained microbiologist of good standing be employed to head this department.

Power Salvage*

By J. P. Foster

I have been requested to write a paper upon the subject of power salvage, meaning the power which may be derived from the useful expansion of steam required for heating purposes in our sugar factories. The same process could just as correctly be called heat salvage, depending upon the viewpoint.

If our primary object is to obtain heat, as in the boiling house, then we may obtain power as a by-product. If, on the contrary, our primary object is to obtain power, then we may obtain heat as a by-product.

Given a definite amount of evaporation to accomplish in the boiling house, with power as a salvage product, we know what type and size of engine to install, and we can closely estimate the amount of power we should be able to obtain, under favorable conditions. Note particularly the qualifying term, "favorable conditions." Each factory is an individual problem for which we have no empirical solution. Some sugar factories may be capable of a high salvage in power, others less than half as much. For the present purpose, I will consider that a factory should produce, as by-product power, not less than 25 k. w. of power per ton of cane ground. Such a factory I would rate at or near 100, consequently a factory capable of producing but 12½ k. w. would rate 50, from a standpoint of efficient power salvage. Assume that we are now about to make a survey of an old sugar

* Presented at the Sixth Annual Meeting of the Association of Hawaiian Sugar Technologists, Honolulu, October 17-20, 1927.

factory with the object of determining what changes, if any, will need to be made in order that its salvage of power shall approach the maximum.

First of all we will look to the back-pressure, and consider means for reducing it, and we will examine the continuity and regularity of steam consumption, and see what can be done to smooth it out. We may find the back-pressure anywhere from 5 to 10 pounds or higher, and that the mill staff believes the equipment of the factory to be such that a reduction in back-pressure cannot be obtained without practically rebuilding the factory at an unjustifiable expenditure.

They believe that the same results may be obtained by raising the initial pressure. In other words, they will obtain by this means the same mean effective pressure as the more fortunate factory where low back-pressure is possible. This cannot equalize, for the M. E. P. does not work out at all in this case, unless we increase the initial pressure 5 pounds for each 1 pound increase in back-pressure. This is shown by the subjoined table of approximate effective equivalents, giving the increase in initial pressure required to compensate for increased back-pressure, assuming the cut-off to be constant.

Approximate Back Pressure (Gauge)	Equivalents Initial Pressure (Gauge)
0 lbs.	100 lbs.
1 "	106 "
2 "	112 "
3 "	118 "
4 "	124 "
5 "	130 "
6 "	136 "
7 "	142 "
8 "	148 "
9 "	154 "
10 "	160 "

From this it will be seen that raising the initial pressure to overcome the handicap of high back-pressure may be even more expensive than a partial renovation of the factory. One frequently hears the salvage power plant spoken of as one of "non-condensing operation." This is not correct unless the steam exhausts into the atmosphere. What happens is that the usual power house condenser is replaced by condensers of various types, shapes and sizes, located in different parts of the factory. There will be condensers functioning as juice heaters, condensers functioning as evaporators, and other condensers serving as vacuum pans. The latter are intermittent in operation instead of continuous. Inasmuch as the back-pressure will be a principal factor in the operation of the power unit, we must see that the condensers are correct.

Three things are essential in the design of a condenser:

1st. Sufficient pipe and inlet area to get the steam to and into it.

2nd. Sufficient cooling area to effect condensation.

3rd. Sufficient outlet and pipe area to carry away the condensate.

Please notice that in the second essential we are not thinking in terms of heating surface, but the contrary, cooling surface. In most, if not all factories, the

surface is fixed, and changes must be made to get the utmost efficiency out of the cooling surface available, and first it is necessary to get the steam up to and into the condenser. Very little if any of our older apparatus was originally designed for low pressure operation. Steam or vapor inlet areas were invariably made too small, and the piping, naturally, was the size of the inlet. If the steam inlet was correctly designed for 10 pounds pressure, we must increase the area 66 per cent for operation at atmosphere, and 100 per cent for operation at 5 inches vacuum. There will be many instances found where the cooling surface could readily condense much more vapor than is supplied to it.

In all probability it will be found, however, that the greatest improvement can be made in the drainage. In the older types of apparatus there was almost never sufficient provision made for drainage, and it is also a fault in most of the more modern apparatus, which is always accentuated where pressure approaches atmosphere. The designer knows that the volume of a pound of steam varies with its pressure, and makes suitable provision for the increased volume.

He then often makes a mistake and figures that a pound of steam condenses to a pound of water, and makes the drainage areas accordingly. Actually, there may be two or more pounds of water to each pound of steam, for we are dealing, not with ordinary saturated steam, but with what we may term super-saturated steam.

There is ordinarily a considerable amount of condensation in the steam lines, and that condensation will often concentrate in certain lines, which, if used as supply lines for condensing apparatus, will result in far more than the calculated water due to the steam entering the condenser.

Much of this water may be entrained, that is, carried in suspension by the steam, so that ordinary bleeders or drain pipes are of little avail.

The drainage trouble is usually worse where the inlet pipes are of insufficient area, as then the steam velocity is correspondingly greater, resulting in more water being carried by entrainment, as well as more being swept along the pipe surfaces. A good rule to follow in drainage problems is to make sure that you are right. Then double the area, and you will be nearer right as well as safer.

Taking the three condenser essentials in the order of their importance and inversely in the order of their cost, we have drainage, steam supply, and cooling surface. Due to the much smaller areas of the pipes, the drainage can be increased very easily and cheaply. The steam supply lines are more expensive to install, but do not ordinarily offer great difficulties, particularly as riveted sheet steel can be used to advantage on the large sizes. I previously stated that the cooling surface is not usually capable of increase. This, of course, does not refer to the installation of additional apparatus, but to the fact that, while we may pipe more steam to a heater or an evaporator, and can pipe more water away from it, we cannot readily increase its cooling, or condensing area. This does not altogether apply to vacuum pans, however.

The old type coil pans should be changed to calandria pans, and many of the earlier calandria pans may, with advantage, be provided with greater areas.

Generally speaking, areas of less than 1½ square feet to the cubic foot of massecuite could be advantageously increased. The expense of so doing is not

necessarily great, for steel tubes and sheets are not expensive, and can often be readily constructed on the plantation if the flat sheet type is used. If correctly designed for circulation they will be found to be very satisfactory.

This statement will probably be challenged on the grounds of alleged short life and alleged low efficiency. As to the life of the steel, such a calandria has been in use at Paia for over ten years and is apparently good for as many more. If massecuites are sufficiently acid to attack the steel, the loss of a calandria will be an insignificant part of the total loss. With regard to the efficiency, the criticism is based upon the lower co-efficient of heat transmission as compared to copper. In this respect it must be remembered that the heat receptivity of a sugar solution decreases very rapidly as its concentration increases. A 60 per cent syrup or a massecuite cannot absorb heat as rapidly as a steel tube can transmit it, so that the limiting factor is not the capacity of the tube to transmit the heat, but rather the capacity of the strike to absorb it.

For example, the heat receptivity, or thermal capacity, if you will, of juice entering the first cell of the evaporator will be about .93; entering the second cell, .84; entering the third cell, .73; entering the fourth cell, .62; and entering the pan, .41; while the average over the duration of the boiling of the strike will be .23.

From the above it would seem that not only the pans, but also the third and the fourth cell calandrias could be profitably made of steel, and possibly the second cell as well.

However, if one wishes to pay for a higher co-efficient of transmission than can be utilized, I have no further argument in that respect.

Having now gone over all of our condensers, and corrected, where possible, the deficient steam supply and the inadequate drainage, we will next see what can be done to get rid of peaks and valleys in our steam consumption curve.

Obviously, if a constant power load is being carried, up to the full steam requirements of the factory, there are but two alternatives to avoid exhausting steam to the atmosphere. If the steam demand is fluctuating widely, we must have, to furnish power during periods of depressed steam demand, a conventional full condensing equipment, with reduced live steam for make-up during periods of maximum demand; or else we must make the demand practically uniform.

By fluctuating demand I do not mean periods when the mill is shut down for any cause, but fluctuations due to the boiling house requiring greater or less amounts of steam during normal operation of the factory. It is assumed that the demand of the heaters and evaporators will be practically constant, and that such large fluctuations as may occur will be due entirely to pan operation.

A pan going off or going on will naturally cause a sharp variation in steam demand, and the only way in which this can be equalized is by careful planning of the pan cycles so that they may overlap. If, for example, we have four pans, a little care and forethought in the boiling house can so arrange the pan cycles that the steam demand becomes practically constant. Close cooperation between pan floor, power house, and the boiler room can go far towards making a bad condition tolerable, and its lack will most certainly make an otherwise favorable condition intolerable.

A signal system should be installed by means of which the pan men notify both the power house and the boiler room of impending changes in the load. Such a system is now in use at Paia. There is in each, power house and boiler room, a signal board equipped with a large electric gong and numbered red and blue lights.

Five minutes before starting any pan, the pan man throws a switch on that pan. A gong rings simultaneously in both power house and boiler room. The operators then look up to the signal board and see a red light on a certain number and both know that the pan of corresponding number will start in five minutes.

Five minutes before stopping a pan, the switch is again thrown, the gong rings, the red light goes out and a blue light appears. By this means both power house and boiler room not only have ample notice of changes and can arrange accordingly, but a glance at the board shows them what pan load is on and they can easily anticipate changes long before they occur. Also, the changing lights show if the pans are being properly overlapped or not, and attention is directed to an unsatisfactory manipulation. If there is lack of cooperation, no amount of skill on the part of the power house operator can avoid fluctuations in back-pressure.

A sudden and unexpected drop in the steam demand will result in a sharp rise in back-pressure, which will cause the power house to consume more steam and consequently cause higher back-pressure due to the vicious cycle at once set up.

To show the effect of this upon the generating unit, we will assume it to be a 1000 k. w. 80 per cent p. f. Cross Compound Corliss unit carrying constant full load with 100 pounds initial pressure, the steam consumption in pounds per k. w. h. will vary with the back-pressure as under:

Back-Pressure	Pounds Steam per K.W.H.
0	32.34
1	33.00
2	33.66
3	34.33
4	35.00
5	35.70
6	36.40
7	37.12
8	37.84
9	38.60
10	39.35

Such a condition will also require a readjustment of the valve settings on the heaters and evaporators, to be again changed when conditions return to normal, but in the interval dirty juice has entered the evaporators, and light syrup has gone to the pan supply tanks.

It is evident, therefore, that plans for a power salvage installation must go much beyond planning the power house, and that the personnel for its successful operation are not the power house employees only.

A Better Understanding of Pokkah Bong and Twisted Top of Sugar Cane

By H. Atherton Lee

Introduction

In 1898, Wakker and Went* described and illustrated in colors a disease of sugar cane called *pokkah bong*. The words pokkah bong are from the native Javanese dialect and, translated into English, mean twisted top. The disease has been mentioned frequently in the 30 years since that time; it has always seemed rather obscure in nature and but vaguely understood.

The disease is not common in Java at present. It occurs in the Philippines on but one variety, a cane which is used by children for chewing and eating rather than for commercial sugar production; the disease is therefore not of commercial importance in the Philippines. It was first reported from Louisiana on some of the P. O. J. varieties by Dr. E. W. Brandes in a short note in *Facts About Sugar*. Dr. Edgerton has also made mention of the disease in Louisiana on the P. O. J. varieties, in a bulletin from the Louisiana State Experiment Station.

In Hawaii, we have a trouble rather commonly found on the variety H 109 which has been called pokkah bong, twisted top, top knot and various other names.

Most pathologists, among them the writer, seem to have regarded the Java form of pokkah bong as an infectious disease. Dr. Brandes, however, stated that the disease was physiological. On his recent visit to Hawaii, Dr. Went expressed the opinion that the Java pokkah bong was quite distinct from the twisted top in Hawaii. This had been the view held by the writer, although the data presented in this paper have altered this view.

The disease, using the word disease to include any injuries to the cane plant, non-infectious as well as infectious, in Hawaii, on the variety H 109, has the following characters: One notices that some of the tall cane stalks appearing above the usual height of a cane field do not have their leaves expanded normally, but a mass of closely wrapped, twisted ribbons of leaves. Examining more closely one will observe that many of the leaves are split and the growing mass of the cane top is wrapped around by such split leaves. The outermost leaves of the bunched cane top are the usual green color of normal leaves, but the younger inner leaves are of a greenish yellow color. Moreover, these younger inner leaves are not of the usual texture of normal leaves, but are buckled and corrugated and have somewhat the character of crumped cabbage leaves. These inner leaves are very rigid and seem to be under considerable mechanical tension. Canes occurring naturally in the field with such an appearance are shown in Fig. 1.

Less advanced stages of the disease are sometimes seen in which the whole top of the cane is not tied up, but the tips of the leaves as they emerge from the

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* Wakker, J. H., and Went, F. A. F. C. De Ziekten van het Suikerriet op Java. E. J. Brill, Leiden, 1898.

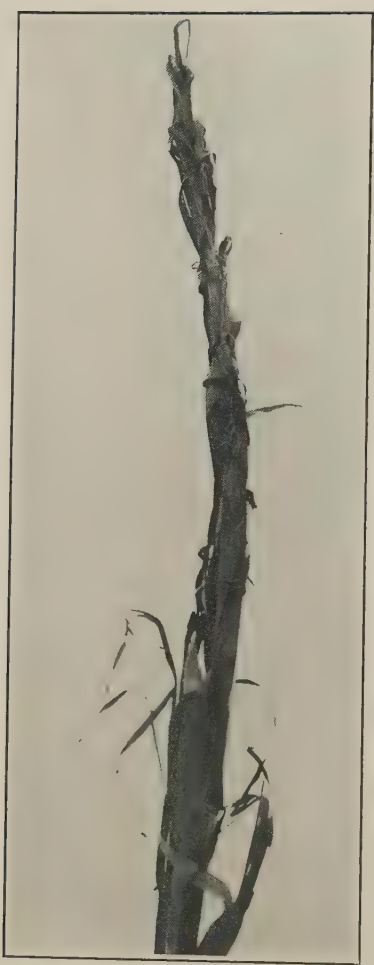

Fig. 1. A naturally occurring case of twisted top in severe form on H 109.

Fig. 2. A mild case of twisted top on H 109 showing arched appearance of leaves; this is also a natural case.

growing point do not separate from each other. Such cases with the lower parts of the leaf blades distended but tied together at their tips have an arched appearance; such a case as it occurred naturally in the field is shown in Fig. 2.

Observations on the Occurence of the Disease in the Hawaiian Islands

The summer of 1926 in the Hawaiian Islands was a period of unusual drought. In the fall of 1926, an unusual occurrence of twisted top occurred at both Ewa Plantation, on Oahu, and Pioneer Mill Company, on Maui. One should note that both of these plantations are on the leeward extremes of the Islands on which they are situated, and both plantations grow H 109 cane under conditions of unusual atmospheric aridity; irrigation in general is by furrow. The disease became so severe in the fall of 1926 that there were a number of cases of top rot observed following the severe tying up of the leaves.

One observation which was recorded was that the disease was of much more common occurrence around the edges than in the middle of the field.

Also it was noted that the large actively growing second shoots or suckers were the stalks usually affected rather than the primary, more slowly growing canes of smaller diameter.

A third observation was that the disease was much less common in experiments where overhead irrigation was being employed than in the fields with the usual furrow irrigation.

With this background of observations many theories were formed and discarded. The theory which has been proven with some success was developed from a remark made by Norman King, agriculturist of the Pioneer Mill Company. Mr. King and the writer were examining affected stalks. It was accepted that the first step in the progress of the disease was the failure of the young emerging leaves to separate at the tips. This was very evidently due to the deep corrugations in the leaf tips which enmeshed the tips of the leaves. Mr. King remarked that it looked to him as if there was some cause of friction as the leaves were emerging from the central cylinder of the cane top, and this friction caused a buckling of the leaf when it was in a young and formative age, which became fixed as the leaf became more mature and hardened.

This view appealed to the writer, for in a previous study of leaf structure, the presence of short rigid hairs or bristles was observed on H 109 leaves, usually at the tips of the leaves and also along the leaf edges. There are two types of hairs on H 109. The hairs of the first type are larger and occur most commonly near the leaf tips. The hairs of the second type were pointed out by D. M. Weller, of this laboratory, and are shorter and more rigid; they are curved upward and occur principally on the lower surfaces of the leaves. A photomicrograph by Mr. Weller of these hairs is shown in Fig. 3. Such hairs would afford a considerable cause of friction of the youngest, most rapidly growing leaves. This friction occasioned by the leaf hairs was visualized as causing a gripping of the youngest leaves against the older leaves causing a cessation of advance until the pressure of growth became so severe as to force a release, when there would be a second gripping and a second release. This alternating gripping and releasing of the leaves when they were in the young, soft, formative stage was visualized as the cause of the fixed corrugations in the leaves when they emerged from the central cylinder.

There were several observations of the occurrence of this trouble which fitted in with this theory. First, the common occurrence of the corrugations at the tips and edges of the leaves, correlated with the position of the longer hairs on the leaves. Secondly, the occurrence of the twisted top most commonly on plantations with an arid atmosphere would mean that there would be less dew on such plantations, and consequently less lubrication for the young, vigorously advancing leaves as they emerged from the central cylinder. The absence of the trouble in cane with overhead irrigation would also correlate with this observation as regards an arid atmosphere.

Thirdly, it has been shown experimentally that when plants of a given species are removed from a humid atmosphere to an arid atmosphere the numbers of

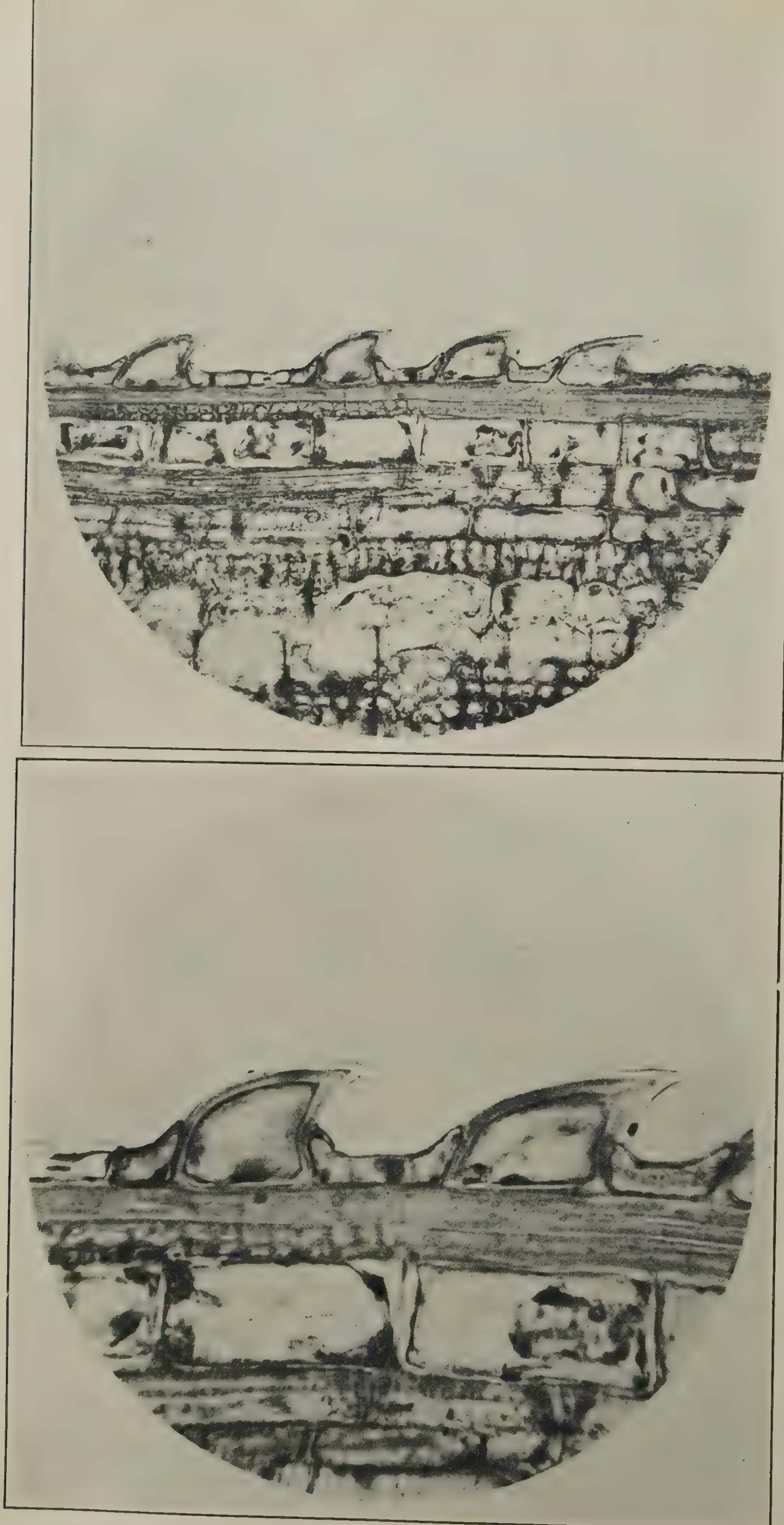

Fig. 3. Photomicrographs by D. M. Weller. The upper figure shows the bristles on the lower surfaces of H 109 leaves magnified X50. The lower photomicrograph shows two of the same hairs magnified X150. These hairs curve upward on the leaves and produce the gripping of the younger leaves against the older leaves as they are pushing out from the central cylinder.

leaf hairs are greatly increased on the leaves which subsequently emerge in the arid atmosphere. Conversely removing plants from an arid atmosphere to a humid atmosphere results in a lessened formation of leaf hairs. A fourth correlation exists in the varieties which are commonly affected with this disease and the abundance of leaf hairs on such varieties. For instance, the varieties H 109 and H 456 are very commonly affected with twisted top and have an abundance of short, bristly leaf hairs at their tips. On the other hand, the production of leaf hairs on such varieties as Yellow Caledonia, Badila and Striped Mexican is considerably less, and on these varieties twisted top is very seldom observed.

The theory at this stage seemed possibly somewhat bizarre, but correlated well with the field observations. What was necessary to establish the theory was an experiment to remove the friction and so bring about a recovery of or avoid the disease; this seemed very difficult, for no way seemed evident to remove the leaf hairs from the young leaves in the central cylinder without destroying the cane top. An alternative suggested itself, to increase the friction on such young leaves while they were still in the central cylinder and thus produce the disease artifically; such an experiment would rather definitely substantiate the theory if the disease was reproduced. This was therefore attempted as follows:

Experiment 1

An attempt was made to reproduce twisted top by increasing the friction of the young, actively advancing leaves as they emerged from the central cylinder.

In this experiment 20 stalks of plant H 109 cane, about six months old, were selected. The central cylinder of young, still unfolded leaves on these 20 stalks, was bound closely, but not too closely, with a six-inch strip of ordinary black friction tape, or bicycle tape, about 1 inch wide. The purpose of this was to create friction between the younger, newly emerging leaves as they advanced upward in the central cylinder, and the other leaves still tightly rolled in the central cylinder of the cane top. Ten of the stalks had the leaves of the central cylinder bound near their tips, while the other ten had the leaves bound near their bases.

The photographs reproduced in Figs. 4 and 5 show the results obtained on the stalks in which the central cylinders of leaves were bound at their bases. There was a fine reproduction of twisted top resulting from this increased friction at the bases of the young leaves. Fig. 4 shows the early stage of development, with the leaves so corrugated that their tips are entangled, presenting an arched appearance as they emerge, and try to separate but are enmeshed at their tips. Fig. 5 shows a later stage of the disease where the next emerging leaves have been obstructed by the arched, entangled leaves, and these new leaves have split through the older leaves; the split older leaves then have a tendency to tie up and increase the friction on the younger leaves, accentuating the twisted top condition.

Of the ten stalks in which the central cylinders of leaves were bound at the bases, all resulted in more or less severe cases of twisted top. Of the stalks on which the central cylinders were bound near the leaf tips, the leaves grew ahead and pushed the tape off in a few days, thus releasing the pressure on the next youngest leaves, with no permanent injury.

Fig. 4. A case of twisted top in the early stages, produced artificially on a stalk of H 109, by increasing the friction on the young, newly emerging leaves. This friction was created by binding the central cylinder of emerging leaves with friction tape; the tape is seen on the older leaves hanging to the right.

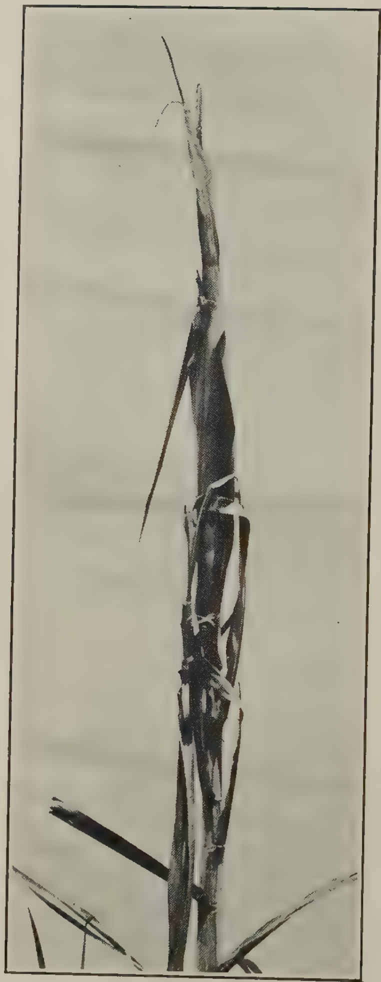

Fig. 5. A more advanced case of twisted top produced on a stalk of H 109 by increasing the friction of the young, newly emerging leaves. This friction was created by binding the central cylinder of emerging leaves with friction tape as in the case shown in Fig. 4. The tape is seen on the older leaves hanging to the left.

Experiment 2

The experiment was repeated with 20 stalks, on ten of which the central cylinders were bound with an elastic tire tape and ten with the same friction tape. The central cylinders with the elastic tire tape exerted so much pressure that the tape was broken and no twisted top resulted. The ten central cylinders bound with the friction tape again resulted in typical twisted top, some of them extremely severe. An illustration of two of these cases is shown in Fig. 6.

Fig. 6. Two severe cases of twisted top on stalks of H 109 produced by increasing the friction on the young leaves as they were emerging from the central cylinder.

Arthur F. Bell, of the Queensland Government Bureau of Sugar Experiment Station, saw these results, and it may be of interest to quote from his letter written to the writer concerning the results:

While visiting the pathology plot this morning I was very interested to observe the malformation of the cane tops of H 109 which you have produced by artificially increasing the friction between the growing leaves. The effect produced immediately struck me as being identical with a condition which we have observed in Australia, and which we have somewhat loosely called ''Pokkah Bong.'' From a few rather casual observations it seemed to me that this ''Pokkah Bong'' was associated with heavy soils where, following a period of dry weather and slow growth, rapid growth was suddenly resumed after a fall of rain.

During this work it was observed that on some of the less hairy varieties, such as D 1135, a few sporadic cases of twisted top would occur throughout a field, showing a difference in character of distribution as compared to the distribution

of twisted top on H 109, the latter type usually occurring only along the edges of fields. This gave rise to a third experiment as follows:

Experiment 3

Twenty cane stalks were selected and marked, but instead of binding with friction tape, the central cylinders of young leaves were bent abruptly about midway in their height. The theory in this was, that such a bend would put pressure on the young, newly formed leaves, causing corrugations of the leaves and ultimate splitting of the older leaves which would cause the typical tying up of twisted top. Such a bending of the central cylinders could easily be occasioned

Fig. 7. A case of twisted top of H 109 produced artificially by simply bending the central cylinder of leaves so as to obstruct the emergence of the still younger leaves within. This obstruction then causes buckling and twisting of such young leaves with the formation of corrugations of the leaves as in the case of the twisted top by increased friction.

by a strong wind, or in young cane by laborers or work animals as they pass down the rows of cane.

This experiment also gave positive results, all of such stalks with abruptly bent central cylinders resulting in twisted top. One of these cases is shown in Fig. 7.

Experiment 4

A fourth experiment was put in at the Pioneer Mill Company, on Maui, using bicycle tape as in Experiment 1 to increase the friction on the young, newly emerging leaves. The results of this experiment may be best presented by quoting from a letter from Mr. King, who cooperated in the experiment:

> In regard to the curly top test at Pioneer, the following are the results:
>
> Visited the test first about a month and a half after starting, and then twice after that. Although but a few marked stalks could be located in the casual observations, I noted that in every case where the tape was successful in maintaining its position about the leaves, curly top was conspicuous. Of the untreated stalks none could be seen that were developing curly top.
>
> Today I made a systematic search for the labeled stalks, and although not able to locate all of them, found 13 of each, making a total of 26. We labeled 20 each, with a total of 40 in the beginning. Three of the stalks marked ''Taped'' had lost their tape and no curling was evident. The other ten all exhibited curliness, but in varying degrees. Five were quite badly curled.
>
> Of the 13 marked ''X'' (no tape) only one showed a slight tendency to curl at the tips of the leaves. Two others had been badly lacerated by passing trains and showed no curling. The remaining 7 showed no signs of curling and apparently were growing normally.
>
> On the whole the test points clearly in favor of the theory that the curly top is the result of friction, made more pronounced by rapid growth.

Conclusion

(1) It seems evident that twisted top as it occurs in Hawaii and probably in Louisiana is a mechanical difficulty and is non-infectious.

(2) The writer, at first inclined towards the feeling that the Java and Philippine form of the disease was infectious and distinct from this form common in Hawaii. With the development of this work, however, one begins to feel that the form in Java and the Philippines might simply be a more severe form of this mechanical injury. One would at least feel doubtful in considering any form of this disease as infectious.

(3) The disease in some of the varieties with short, stiff leaf bristles, may result in arid atmospheres from friction of the newly emerging leaves against the more slowly growing older leaves. This friction results in an alternating gripping and release of these young leaves as they advance, causing a buckling of the leaf tissues. Being in a young formative stage, the leaves which are so retarded and buckled show fixed corrugations when they emerge. These corrugations of the newly emerging leaves become enmeshed and prevent the leaves from separating at their tips as they normally would. The enmeshed leaves form arches against which younger, newer leaves are obstructed, and there is then a consequent greater buckling, and splitting of leaves, which results in typical twisted top.

(4) A mechanical injury to the central cylinder of young leaves of the cane top from wind or the field laborer or work animals may also result in twisted top. It is probable that any injury to the central cylinder of leaves of the cane top, which obstructs the free emergence of the younger, inner, actively advancing leaves, will cause a buckling of the leaves and formation of corrugations on the leaves or splitting of the leaves, and ultimately twisted top.

Experiments Showing the Cause of Leaf Burn of Sugar Cane

By H. Atherton Lee

A disease, known variously as leaf burn, wind burn, leaf scorch, tip burn and occasionally by other names, has been definitely recognized in these Islands since 1920. It is probably the same disease which Cobb described in 1908 as tip wither. It is evident that the disease is not new in the Islands.

The disease is most generally noticed in a field when parts of the leaves are killed and browned. Closer observation shows that the younger leaves are most commonly affected. Such affected leaves are killed along the edges, although occasionally a blotch may appear inside the edges of the leaves and not extend to the margin. The killed areas may extend the width of the leaf blade to the midrib or be a very narrow margin along the edge of the leaf. The midrib does not seem to be affected.

Affected leaves are first a dull, dry-green color, much the same color as the normal leaf except that the gloss and sheen of the normal leaf are lost. The affected parts of the leaf shrivel a little. With time, these dry-green areas fade, become ashen, and then tan-colored. When a cane plant has many of such leaves affected it appears to be stunted. The older leaves are not usually affected.

The disease occurs most frequently along the edges of fields, although in young cane it may be found well distributed throughout the inside of a field. The variety U. D. 1 is rather frequently affected. H 109 is sometimes observed affected, but not as frequently as U. D. 1. One case has been observed on D 1135, but the writer has not observed the disease on other varieties although it probably does occur.

Experiments to Show the Cause of the Disease

The word disease is used here to include abnormalities in the cane which are non-infectious, that is, nutritional, mechanical or genetic, as well as those which are infectious.

Cobb ascribed the cause of tip wither to a fungus. The cause has also frequently been ascribed to electrical disturbances in the air, wind injury and drought. The disease has not caused great concern in H 109, but attention has been occa-

sionally called to it and mild concern expressed regarding its spread. With the advent of the variety U. D. 1, which is more commonly affected, there has been more demand to know its cause and methods of avoiding or combating the trouble.

Although the occurrence of the disease in the field was somewhat suggestive of an infectious agent as the cause, the very rapid spread of the killed areas on the leaves was evidence against this view. Usually the disease showed over the entire surfaces of leaf blades in 6 to 8 hours, an advance much more rapid than would be expected of the most virulent pathogenic organisms. The first efforts to find the cause of the trouble were therefore directed towards determining the effect of physical factors on the cane plant.

Without recounting earlier experiments with negative results, the clue was derived from one of these experiments in which leaves of cane plants, softened by an environment of humid, cloudy weather for a number of days, would burn when exposed to one of the brisk northeast tradewinds, common to these Islands. An experiment was therefore set up as follows: Twenty plants of the variety U. D. 1 were grown in concrete pots until 2 months old. They were then fertilized with nitrate of soda and after an interval of 10 days placed in a moisture cage, with high humidity and the sunlight considerably screened. After several days in this environment the plants were removed to a greenhouse with a rather dry air. Ten of the plants were placed upon a table about 10 feet in front of two 15-inch oscillating desk fans; the other 10 plants were placed in the rear of the desk fans, where they were subjected to the same environment, but without being subjected to the breeze of the fans.

The fans were allowed to play on the ten plants from 9:30 a. m. to 5:30 p. m. and then stopped. At the end of that time the youngest leaves of the cane plants in the breeze showed the dry-green color and shriveled edges of typical leaf burn in its early stages. The control plants, not exposed to the breeze, remained entirely normal.

In two days the plants which had been subjected to the breeze for 8 hours showed the younger leaves shriveled, faded, and ash-colored, and in one week such plants had gone through all the typical stages of leaf burn.

At this stage the conclusion seemed to be that leaf burn was really wind burn. However, subsequent experiments slightly modified this view.

The experiment was repeated in order to corroborate these results. In the second experiment the potted plants of the variety U. D. 1 were not fertilized with any nitrogen fertilizers. They were subjected to the same seven days in the moisture cage, with high humidity and sunlight reduced, as in the case of the potted plants in the previous experiment. Ten of these potted plants were placed before two oscillating desk fans and 10 plants were kept protected from the breeze as controls, as in the previous experiment. The fans were allowed to play for the same length of time. After 8 hours of such breeze there were only very slight evidences, if any, of leaf burn on the plants exposed to the fans. The controls remained normal.

The results of this experiment were inconclusive and seemed to fail to corroborate the results of the first experiment. It was suspected, however, that the difference in results was caused by the non-application of nitrogen fertilizers.

A third experiment was therefore carried out. In this case 20 potted plants of the variety U. D. 1 were fertilized with nitrate of soda, and after an interval of a week were placed in moisture cages for 8 days in an environment of high humidity and lessened sunlight. Ten of the plants were then placed on a table before two oscillating desk fans and the remaining 10 plants placed on a second

Fig. 1. At the left four healthy control plants. At the right four plants showing leaf burn produced artificially by increasing transpiration by means of a breeze from oscillating desk fans. All plants are of the variety U. D. 1 and had been treated previously with nitrogen fertilizers and submitted to an atmosphere of high humidity.

Fig. 2. A closer view of the four plants of U. D. 1 with the artificially produced leaf burn, shown in Fig. 1. The ashen-colored leaves and somewhat shriveled edges and tips of the leaves typical of leaf burn are shown.

table, but to the rear of the desk fans. The fans were played on the first 10 plants for 8 hours. The day was unusually dry with a bright, strong sunlight through the clear glass roof of the greenhouse.

At the end of the 8 hours' exposure to the fans the 10 treated plants showed abundant leaf burn. However, some of the 10 control plants without the breeze also showed a slight degree of leaf burn. The results are shown in the photographs reproduced in Figs. 1 and 2.

Fig. 3. At the right, five of the ten fertilized plants with leaf burn resulting from being subjected to the breeze of two oscillating desk fans for eight hours. At the left, five of the ten fertilized plants placed as controls in the rear of the desk fans. All plants are of the variety U. D. 1 and had been treated with nitrogen fertilizers and then subjected to eight days of an environment of high humidity and decreased sunlight.

Fig. 4. At the left, five plants which had received no nitrogen fertilizers, and at the right five plants which had received nitrogen fertilizers. All plants are of the variety U. D. 1 and were subjected to an environment of high humidity and lessened sunlight for eight days and then exposed to the breeze of two ordinary oscillating desk fans for eight hours. As is evidenced in the illustration, the plants with the nitrogen treatment showed abundant leaf burn, while the plants with no nitrogen showed but one mild case of leaf burn.

Fig. 5. The five control plants which had received no nitrogen. They were placed in the rear of the desk fans and shielded from the direct rays of the sun by a screen of thin cheesecloth. These plants all remained normal and showed no symptoms of leaf burn.

The conclusion reached from this experiment was: that leaf burn did not result alone from wind on soft, succulent leaf tissues, but that after an environment of absence of sun and high humidity, plants subjected to excessive transpiration caused by either wind or intense sunlight would result in leaf burn. It also seemed probable that nitrogen fertilizers placed the plants in a condition in which they were more susceptible to leaf burn. These results were not entirely conclusive, however, for we had no controls which had not been subjected to strong sunlight.

A fourth experiment was therefore undertaken as follows: Thirty potted plants of the variety U. D. 1 were grown, of which twenty were treated with nitrate of soda as a source of nitrogen fertilizer. All 30 plants were then placed in the moisture cage where they were submitted to an environment of high humidity and diminished sunlight for 8 days. All 30 plants were then removed to the dry greenhouse. Ten of the 20 plants which had received nitrogen fertilizer, and 5 of 10 plants which had received no nitrogen fertilizer, were placed upon a table in front of the 2 oscillating desk fans. The remaining 10 plants of the 20 which had received nitrogen fertilizer, and the 5 plants with no nitrogen fertilizer, were placed as controls on a table in the rear of the desk fans. These 15 control plants were shielded from the direct rays of the sun by a thin screen of cheesecloth. The fans were then allowed to play on the first 15 plants for 8 hours.

At the end of 8 hours the 10 fertilized plants standing in the breeze showed severe leaf burn in every case. Of the unfertilized 5 plants standing in the breeze 4 showed no leaf burn and the fifth showed but a mild case of leaf burn. These results are shown in Figs. 3 and 4.

Of the 15 controls standing in still air, and protected from above by the cheesecloth screen, one plant at the west end had received the afternoon sun; it showed moderate symptoms of leaf burn. The other control plants all remained normal. These results are shown in the photographs reproduced in Figs. 3, 4 and 5.

The conclusions reached from this last experiment are that:

Leaf burn results from excessive transpiration which may be occasioned by either a steady, constant, brisk breeze or intense sunlight. This leaf burn occurred only on the plants which had recently received nitrogen fertilization. The disease is clearly non-infectious.

Discussion

In view of the fact that excessive transpiration occasioned by sunlight as well as wind, will cause this disease, it is preferable to apply the name of leaf burn, rather than wind burn to this trouble. The action of the wind or sunlight, or possibly the two together in some instances, apparently results in a removal of the moisture from the leaves more rapidly than it can be supplied from the stalk and roots. Nitrogen fertilizers seem to increase this transpiration. The experiments show, that with varieties susceptible to leaf burn, nitrogen fertilizers should be applied with discretion as regards probable weather factors. The injury to the leaf apparently results from a collapse of the cells in the leaf tissues following a too rapid loss of moisture.

Leaf burn in some instances may cause a greater injury than merely a reduction of leaf area. If the transpiration of the leaves is increased gradually, there is a translocation of nutrients by the plant to the leaves, apparently to protect the leaves from excessive transpiration. If, in spite of this, leaf burn results, there is a loss, not only of leaf area, but also a considerable supply of elaborated plant materials as well as inorganic nutrients. This would explain the considerable stunting which has been observed in stools of cane affected with leaf burn. This was first pointed out for wind burn of the foliage of citrus trees by Haas and Reed.*

When the foregoing results were obtained a search of the literature was made to see if there were similar troubles in other crop plants. It was found that leaf burn of sugar cane apparently is not an isolated instance of injury from excessive transpiration. There is a leaf burn of citrus trees in California shown to be caused by excessive transpiration resulting from dry winds. The late Dr. F. C. Newcombe, formerly Professor of Botany, University of Michigan, cited an instance of leaf scorch of maple trees caused by drying winds following warm, humid weather in summer months. A leaf scorch of orchard trees, which would seem to be a somewhat similar trouble, is known in England.

A possible factor in this leaf-burn injury in relation to weather has been brought out in discussion by D. M. Weller, of this laboratory. He points out the research by Priestly, showing that leaves formed in a humid environment have less cuticle than the leaves of an identical plant formed in an arid environment. Thus the susceptibility of cane to leaf burn following 8 or 10 days of kona weather, might in part be explained by the lessened cuticle of the leaves emerging during the kona period.

* Haas, A. R. C., and Reed, H. S. Relation of desiccating winds to fluctuations in ash content of citrus leaves and phenomenon of mottle leaf. Botanical Gazette, Vol. LXXXIII, No. 2; April, 1927, p. 161.

Methods to Minimize Leaf Burn

In view of the foregoing results it is possible to mention a few measures which might be undertaken to diminish leaf burn if the injury to the cane warranted attention.

Leaf burn in H 109 and D 1135 is so rare and causes such negligible injury that it probably can be disregarded.

With the promising new variety U. D. 1, in which injury is more common and more severe, the exercise of some discretion in the use of nitrogen fertilizers in relation to the weather probabilities should considerably minimize the trouble. If drying, leaf-burn weather occurs unexpectedly, following a week of kona weather and about two weeks after nitrogen fertilizer applications, an irrigation to increase the atmospheric humidity would have a minimizing effect in decreasing the excessive transpiration.

Although windbreaks are in some cases decidedly disadvantageous, in the case of fields of U. D. 1, they would be advantageous should leaf burn ever become a very considerable factor.

Summary

1. Leaf burn of sugar cane is a non-infectious disease.
2. It is caused by excessive transpiration of the leaves as shown experimentally by subjecting potted cane plants to the breeze of oscillating desk fans, or intense sunlight.
3. Nitrogen fertilizers predispose cane plants to leaf burn.
4. There is a loss resulting from the disease, not only of the leaf area which is killed, but also of a supply of nutrients and elaborated food materials translocated to the leaves which are transpiring heavily. This loss of nutrients probably explains the stunting effect of leaf burn on affected cane plants.
5. Injuries from excessive transpiration similar to leaf burn of sugar cane have also been established on other crop plants.
6. The disease is not infrequent in the variety U. D. 1 and is occasionally found in H 109. It has been observed on D 1135, but has not been observed on the other standard varieties of these Islands.
7. The disease being clearly non-infectious, it seems probable that it can be disregarded on such slightly affected varieties as H 109 and D 1135. Of the variety U. D. 1 some attention to the time of application of nitrogen fertilizers in relation to the probabilities of weather conditions may aid in avoiding the trouble. In periods of drying winds irrigation to increase the atmospheric humidity would be a measure to minimize the injury slightly. Windbreaks would also have a value in this instance.

Oliver Filter Operation for 1927

By H. F. Bomonti

The data contained in this report were taken from the laboratory and boiling house records. It is with the consent of E. W. Greene, Manager; C. J. Fleener and H. W. Robbins, of the Oahu Sugar Company, Limited, that they are presented in this report.

The Oliver filter was put in operation December 4, 1926, and was used throughout the entire grinding season ending July 16, 1927. Stoppages occurred for the following reasons only: washing of filter cloth, changing the cloth, repairing the filter drum, and when the mill was shut down. So far as the writer is aware, at no time did the filter fail to function properly due to poor filtering settlings. At all times, this filter was considered an integral part of the filter station.

Before taking up the performance record of the Oliver filter, it seems more appropriate to discuss the changes and improvements that were either made or contemplated this year.

Two minor changes were made during the year. First, the spray nozzles were mounted in brass pipes throughout the entire system. This was done to eliminate the scale deposits, due to iron pipes, which had a tendency to plug up the very fine perforations in the spray nozzles. Second, the scraper, which is used to discharge the cake from the cloth, was lowered about 10 inches. Lowering the scraper would increase the time interval by 20 seconds after the cake had passed under the last row of spray nozzles and until it was discharged. Increasing the cycle at this phase of the operation would tend to produce a cake of slightly lower moisture content and also lower in polarization.

Two minor refinements were added to the Oliver filter installation during the year. The filter was closed in with a hood. While this was only a temporary arrangement, it is understood that the new filters will be equipped with hoods of a permanent nature. With the filter covered, the fine spray from the spray nozzles is prevented from escaping into the atmosphere. This results in a more efficient use of the wash water. The cake also is kept hotter, which seems to make it more porous. The second refinement made during the year was the installation of an automatic feed valve. With this automatic feed valve in the line, a uniform level of settlings was maintained in the filter. While a constant level could be maintained with an adjustable overflow, it is both undesirable and uneconomical to use such a device.

For the coming year, the filter will be equipped with a new drum. This drum is made of wood, with brass piping and copper screens. It was found that the present drum which was of iron construction failed to withstand the existing conditions. The pipes and inner surfaces of the drum corroded, with the result that rather large holes developed. Such a condition has a very serious effect on the economical operation of the filter. When such leaks develop, the formation of the cake is affected as well as the sweetening-off of the cake.

The data have been arranged in two tables. The form of these tables is about the same as that used in Table XXI of "The Report on the Treatment of Settlings and the Oliver Filter," *The Hawaiian Planters' Record,* Volume XXXI, January, 1927.

Table I gives the average figures of capacities per day and per hour for periods varying from four to five weeks and also the averages for the entire crop.

Discussion of Data

Item 4. Settlings % mixed juice. This figure runs quite uniform for the different months. The minimum, 15.1, is secured in March, and the maximum, 20.2, in July. A spread of only 5.1 per cent between the minimum and maximum is very small.

Item 7. Tons settlings filtered by the Oliver filter per hour. During the first two months the lowest capacities were secured. These were 6.4 and 6.3 tons settlings filtered by the Oliver per hour. The capacity showed a small increase during the months of February, March, and April. In May, June and July there was a marked increase in capacity over the previous months. These variations in capacity are undoubtedly due to the change in composition of the cake solids. During the first few months, winter months, there is apt to be less fiber in the suspended solids. While in the latter part of the season the fiber would tend to increase. It has been quite definitely established that as the percentage fiber in the cake increases, greater capacities are secured.

Item 8. Cake solids discharged by the Oliver per hour. This is a figure which can be used in making comparisons of capacities. The pounds cake solids discharged per hour show a somewhat greater spread between the maximum and minimum than comparison of tons settlings per hour. Comparison of tons settlings per hour shows a spread of 30 per cent between maximum and minimum, while the pounds cake solids discharged per hour shows a spread of over 50 per cent. The variations follow fairly close to those mentioned in Item 7.

Item 10. Tons cane equivalent to tons settlings filtered by the Oliver per hour. This figure is influenced by the volume of settlings % mixed juice. But where the variation in the settlings % mixed juice is small, the figure has some real significance. It is doubtful whether such a figure could be used to compare the performance of a continuous filter in different factories. The minimum 29.9 tons cane equivalent to tons settlings filtered by the Oliver per hour was secured in February. The maximum, 39.1, was secured in May.

Item 13. Settlings filtered by the Oliver % total settlings. During December and January, the filter averaged 23.9 and 22.4 per cent of the total settlings. The averages for the other months were considerably higher. The maximum was secured in April when 30.4 per cent of the total settlings were filtered.

Item 19. Polarization % Oliver cake. The high polarization in the Oliver cake during December, January and February, is due to several factors. The spray nozzles were plugged quite frequently by scale from the iron pipes, causing irregular washing. The cake was not as porous during these months as later in the year. The flow meter used to measure the wash water was out of order. All these factors tended to produce a high polarization. The polarization of the cake was also high in May. This, the writer believes, was due to mechanical defects in the drum.

		30 days Feb. 28, 1927 to April 2, 1927	24 Days April 4, 1927 to April 30, 1927	24 Days May 2, 1927 to May 28, 1927	30 Days May 30, 1927 to July 2, 1927	11 Days July 5, 1927 to July 16, 1927	Crop Dec. 5, 1926 to July 16, 1927
1.	Tor	2986	2885	2736	2615	2446	2792
2.	Tor	357	350	346	350	307	338
3.	Tor	524	562	532	564	599	556
4.	Set	15.1	16.8	16.7	18.0	20.2	17.1
5.	Tor	5.70	5.13	5.14	4.64	4.25	5.02
6.	Tor	141.3	170.3	146.8	154.0	178.5	149.1
7.	Tor	6.5	6.9	7.6	7.4	8.25	7.10
8.	Cal	442	373	494	548	512	440
9.	Tor	805	874	755	715	759	748
10.	Tor	37.0	35.4	39.1	34.3	35.1	35.6
11.	Ho	21.6	21.5	19.4	20.8	21.7	21.0
12.	Gal	4.9	5.2	5.7	5.55	6.2	5.3
13.	Set	27.0	30.4	27.5	26.7	30.2	26.96
14.	Per	3.4	2.7	3.25	3.7	3.1	3.1
15.	Thi	9/32″	9/32″	5/16″	11/32″	5/16″	9/32″
16.	Tor	29.8	29.0	29.3	28.1	34.0	28.0
17.	Tor	1.38	1.35	1.51	1.70	1.57	1.35
18.	Tor	1.32	1.11	1.52	1.41	1.38	1.36
19.	Pol	0.92	1.08	1.47	0.92	0.71	1.19
20.	Mo	82.65	82.15	81.97	82.44	82.82	82.24
21.	Ra	5.6	6.4	8.8	5.58	4.3	7.18
22.	Pol	2.63	4.10	4.10	4.64	5.16	3.81
23.	Mo	75.5	76.8	70.5	71.5	72.0	73.45
24.	Ra	12.02	21.47	16.14	19.45	22.6	16.76
25.	Est						
		1.23	2.52	1.45	2.44	3.34	1.72
26.	To	1.11	2.27	1.31	2.20	3.00	1.55
27.	Va	$0.26	$0.56	$0.33	$0.55	$0.84	$0.40

It seems doubtful to the writer if the average can ever be maintained below 1 per cent for an entire season. With very great care and constant supervision it can be reduced to well below 1 per cent, but with the type of labor available for this work, this does not seem possible.

For a two-week interval in July, the polarization was 0.71; for June it was 0.92; this was considered very good. The average, 1.19, is slightly higher than the average for the two months run last year.

Item 21. Ratio: Polarization % cake solids. The polarization % cake solids is really the figure which should be used to compare the relative efficiency of press work. In the Oliver cake, the moisture is high compared to press cake, so that calculating results in terms of polarization % cake solids makes them comparative. The average for the crop is 7.18, that is the polarization % cake solids. This would be equivalent to 2.0 per cent polarization in press cake having a moisture content of about 70 per cent.

Table II is a comparison between the averages for the year 1927, and for the two months run during 1926. It is evident from Table I that during the months of May and June, the settlings possess better filtering characteristics than during the winter months. For this reason the averages are not strictly comparative, nevertheless they are interesting.

TABLE II

Performance Record of the Oliver Filter	189 Days 1927	50 Days 1926
Tons cane per day	2792	2852
Tons sugar per day	338	380
Tons settlings per day	556	658
Settlings % mixed juice	17.1	20.6
Tons cane per ton of settlings	5.02	4.33
Tons settlings filtered by the Oliver per day	149.1	161.8
Tons settlings filtered by the Oliver per hour	7.10	7.52
Tons cane equivalent to tons settlings filtered by the Oliver filter		
per day	748	700
per hour	35.6	32.56
Hours filtering per day	21.0	21.5
Gallons of settlings filtered per square foot per hour	5.3	5.8
Settlings filtered by the Oliver % total settlings	26.96	24.80
Per cent suspended solids in settlings	3.1	2.28
Thickness of Oliver cake, inches (calculated)	9/32″	7/32″
Tons of Oliver cake per day (calculated)	28.0	23.35
Tons of Oliver cake per hour (calculated)	1.35	1.09
Tons Oliver cake equivalent to ton press cake	1.36	1.40
Polarization % Oliver cake	1.19	1.14
Moisture % Oliver cake	82.24	83.29
Ratio: Pol. % cake solids	7.18	7.42
Polarization % press cake	3.81	4.69
Moisture % press cake	73.45	73.31
Ratio: Pol. % cake solids	16.76	22.24
Estimated saving in tons polarization when all the settlings are filtered with Olivers, per day	1.72	2.01
Tons polarization available from above item	1.55	1.81
Value of sugar saved per ton of sugar manufactured	$0.40	$0.37
Market value of sugar for 1927....$86.00		
Market value of sugar for 1926....$74.60		

The Purity of the Oliver Filtrate

Routine laboratory samples of the Oliver filtrate were taken over a period of six weeks. These samples represent the total filtrate including the washings. The average purity of the Oliver filtrate and also the average purity of the clarified juice is tabulated below.

	Clarified Juice	Oliver Filtrate	
Brix	13.92	11.90	
Polarization	11.78	9.98	
Purity	84.63	83.87	Difference 0.76

Experimental data secured last year indicated that the difference between the purity of the Clarified Juice and the Oliver Filtrate, including the washings, was about 0.61. The data in the above tabulation show a difference of 0.76 in purity. The writer believes that this agreement between experimental data and factory data is as close as can be expected. Had all the settlings been handled in this way, the above decrease in purity would have depressed the purity of the evaporator supply approximately .15 below the purity of the settled juice. This depression of the purity of the evaporator supply juice is considerably less than is secured under the old system of filtration.

The Yield Equation and Its Application to Sugar Cane Agriculture*

By J. A. Verret and Y. Kutsunai

When the harvesting results of a test on the varying amounts of fertilizer are plotted on a sheet of cross-section paper, with the amounts of fertilizer along the x-axis, the corresponding cane yields along the y-axis, and the resulting points connected by a smooth line, an ascending curve will be formed. It is steeper at the lower amounts of fertilizer than at the higher amounts; in other words, the curve flattens out as the amount of fertilizer increases. The curve shown in Fig. 1 is drawn from actual experimental data.

Such a curve shows at a glance the relation between the varying amounts of the fertilizer and the corresponding cane tonnage not only at the point tested but also at intervening points, and reveals, roughly, where to stop fertilization in order to produce the greatest profit.

A more accurate method of arriving at these critical results is by the use of a yield equation. This will furnish definite information on such important matters as:

1. The maximum amount of fertilizer that can be applied without loss;
2. The amount of fertilizer to use to obtain the highest profit per acre;

* The mathematical work in this paper is entirely by Y. Kutsunai.

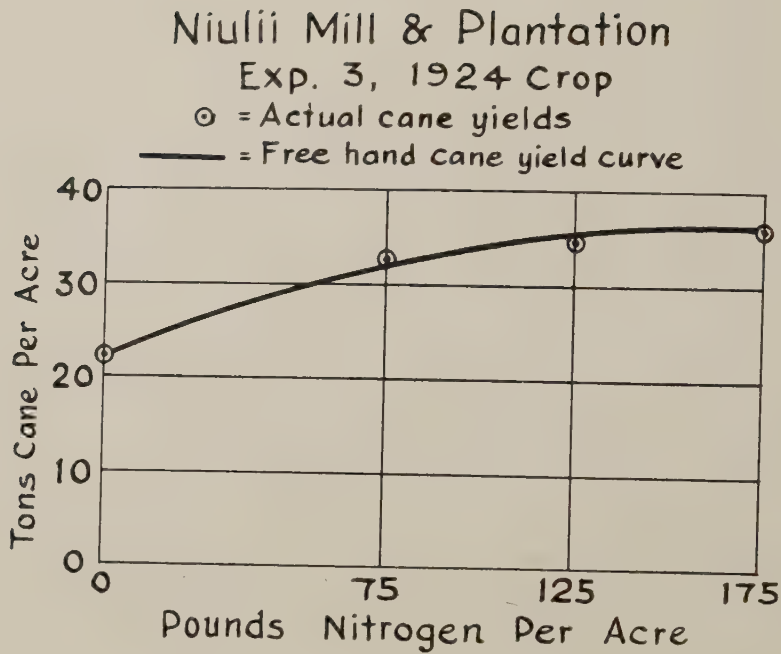

Fig. 1

3. The amount of fertilizer to apply to produce the maximum gain for each dollar invested in the crop;
4. Probable fertility of the field expressed in terms of the fertilizer tested on that field;
5. Accurate determination of the effect of the increase or decrease of a small amount of fertilizer from the standard practice;
6. The comparative efficiency of various forms of fertilizing elements;
7. Determination of the amount of fertilizer that maintains the soil fertility; and
8. The comparative efficiency of different varieties of sugar cane.

Aside from the economic questions that can be answered by means of the yield equation, there are matters of scientific interest capable of solution by the use of this same equation. The latter may include the detection of the limiting factors of growth, establishment of growth factor for the diverse fertilizing elements, and the study of the inhibiting effect of certain soil constituents. However, the present paper is limited to the application of the equation to the economic problems.

Among the many possible mathematical formulae that can be used to express the relation of the yield to the amount of fertilizer, three may be considered important, namely:

Maskell's equation, $Y = \dfrac{1}{k_1 + \dfrac{k_2}{p + P}}$;

Mitscherlich's equation, $\log (A - Y) = \log (A - a)\ kx$;

Spillman's equation, $Y = M - AR^x$.

Of these, Spillman's equation seemed the easiest to understand and to handle, consequently the other two were not followed in detail. The equation, $Y = M - AR^x$, is based on the law of diminishing increments, the truth of which appears to be substantiated by many fertilizer tests. Local fertilizer experiments are cited, for example, of the practical demonstration of the law of diminishing increments.

Makee Sugar Company, Experiment 23, 1927 crop, tested varying amounts of phosphoric acid. The data obtained are:

Pounds Phosphoric Acid per Acre	Tons Cane per Acre	Tons Cane Gained for Each Additional 32 lbs. P_2O_5
144	35.7	...
176	48.7	13.0
208	50.3	1.6
240	50.6	0.3

In this example, the increments in cane yields decrease as the phosphoric acid is increased and the decrease of the successive increments takes place in fairly constant ratios, which are 1:0.12 and 1:0.19. The slight disagreement in the ratios is well within the experimental error since such fluctuation is caused by an error of only 1/10 ton in the third increment.

Pioneer Mill Company, Experiment 23, 1927 crop, is a test on the amount of nitrogen to apply. The harvesting results are:

Pounds Nitrogen per Acre	Tons Cane per Acre	Tons Cane Gained for Each Additional 50 lbs. N.
140	57.5	...
190	67.6	10.1
240	74.2	6.6
290	78.2	4.0

Here again, the increments in cane are decreasing as the amount of nitrogen increases. The ratios of decrease in the successive increments are 1 :0.65 and 1:0.61, which figures are sufficiently close to be considered constant.

The yield equation of Spillman is based on the law of diminishing increments, a law which is founded on the assumption that increasing amounts of fertilizer or water increase the crop, but the successive increments in crop for each additional lot of fertilizer or water are decreasing at a constant ratio. It is interesting at this point to note that the ratios computed closely approximated the actual figures obtained experimentally.

Plantation	Experiments	Actual Ratios	Computed Ratio
Makee Sugar Company.......	23	0.12 and 0.19	0.1519
Pioneer Mill Company........	23	0.65 and 0.61	0.6293

The yield equation of Mitscherlich, although originally founded on other assumptions, can be deduced from this same law.

The harvesting data used in evaluating the terms in the yield equation must, of course, be fairly free of experimental errors, since the equation does not correct errors in the basic data.

In discussing the many uses of the equation, cane tonnage only is considered because the effect of various fertilizers on the quality ratio is not sufficiently well understood to permit the reduction of cane yields to sugar yields with mathematical exactness.

A comparison of the actual harvesting data of Kaiwiki Sugar Company, Experiment 2, 1924 crop, with the calculated cane yields shows a satisfactory agreement.

No. of Lots of Fertilizer	Actual Tons Cane per Acre	Calculated Tons Cane per Acre	Difference Tons Cane per Acre
1	41.6	41.6	0
2	43.6	43.5	—0.1
3	45.0	45.1	+0.1
4	46.6	46.6	0

The calculated cane yields were obtained from the equation, $Y = 59.08 - 19.517 (0.8944)^x$. Each lot of fertilizer was composed of 50 pounds nitrogen and 12½ pounds each of phosphoric acid and potash. Fig. 2 shows the graph.

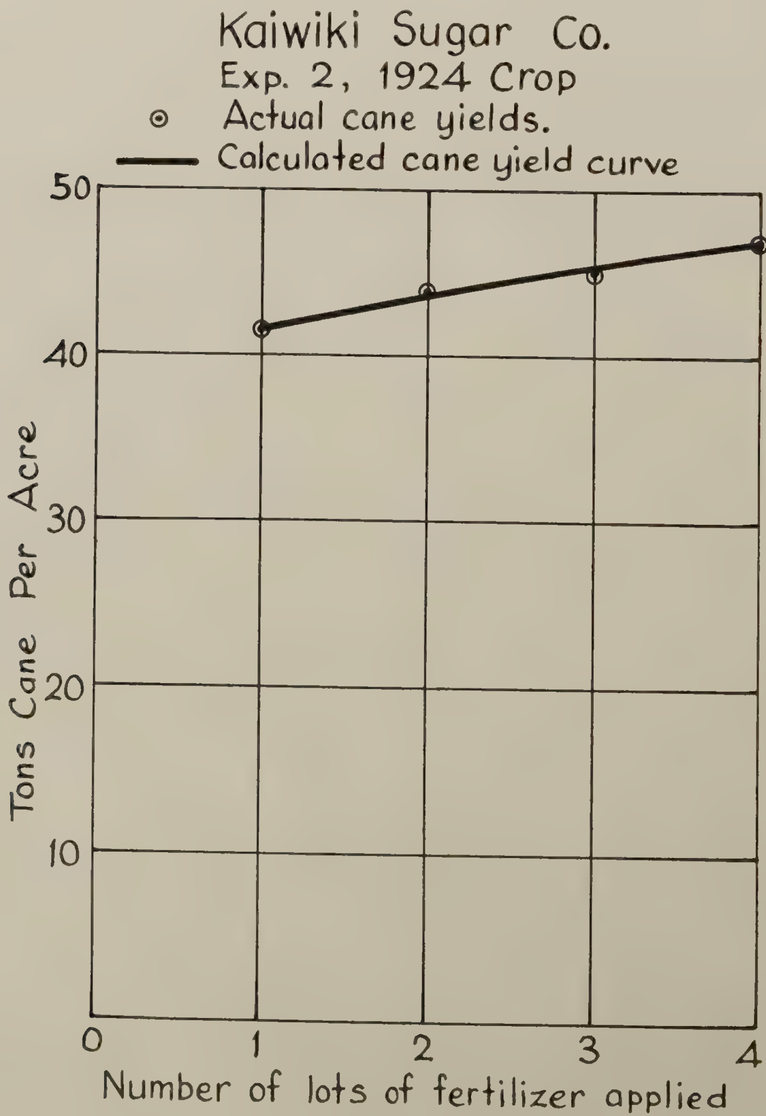

Fig. 2

Another example from Lihue Plantation Company, Experiment 5, 1924 crop, shows the same agreement between theoretical and experimental figures.

Pounds Nitrogen per Acre	Actual Tons Cane per Acre	Calculated Tons Cane per Acre	Difference Tons Cane per Acre
0	27.31	27.29	—0.02
75	39.77	39.86	+0.09
150	47.88	47.81	—0.07
225	52.89	52.89	0.00

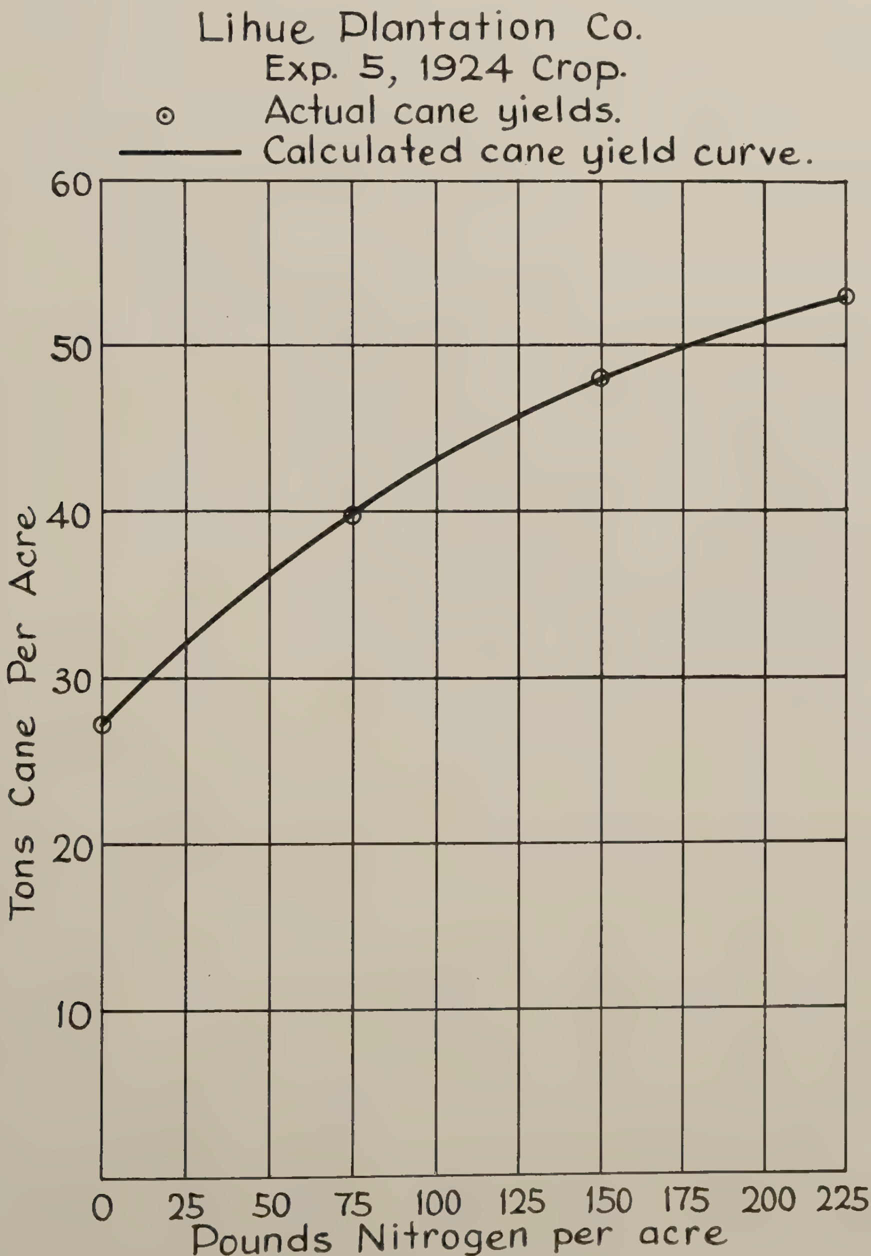

Fig. 3

The yield equation which supplied the calculated cane tonnage is $Y = 61.645 - 34.351\ (0.6341)^x$. Besides the varying amounts of nitrogen, all the plots received 500 pounds of reverted phosphate per acre and a uniform application of molasses ash. Fig. 3 presents the figures graphically.

As the theory of the law of diminishing increments implies, the efficiency of the fertilizing elements declines as the amount of fertilizer applied increases. This tendency is very pronounced in the case of phosphoric acid and potash and less so for nitrogen, and there must be a point beyond which any further increase in fertilization no longer pays. This point may be termed the maximum economical fertilization point at which the cost of additional fertilizer applied to the field is exactly equal to the value of the increase in the crop. Below this the investment in fertilizer brings in profit and above it, a loss. If Q tons of standing cane has the value equal to the cost of one lot of fertilizer applied, the maximum economical fertilization point is obtained by the formula

$$\frac{\log Q - \log\ (-2.302585\ A \log R)}{\log\ R}$$

The formula expresses the total amount of fertilizer up to the maximum economical fertilization point in number of lots of fertilizer. The weight of the fertilizer is, therefore, equal to the number of pounds in the lot multiplied by the number of lots of the fertilizer.

A numerical example may clarify this explanation. If one lot of nitrogen applied to the field costs \$18 and the value of a ton of standing cane be \$2.50, the amount of cane needed to balance the cost of one lot of nitrogen is $18 \div 2.50 = 7.2$ tons. Using the values A and R in the yield equation, $Y = 61.645 - 34.351\ (0.6341)^x$, of Lihue Plantation Company, Experiment 5, 1924 crop, as cited previously, the maximum economical fertilization point is

$$\frac{\log 7.2 - \log\ (-2.302585 \times 34.351 \log 0.6341)}{\log\ 0.6341} = 6.759.$$

Each lot in this experiment was 75 pounds of nitrogen, hence the maximum amount of nitrogen that can be applied without a loss is 75×6.759 or 507 pounds. This amount is not to be used in practice, however, because costs other than the actual purchase price of the fertilizer cannot be disregarded, and what is desired is not the highest tonnage of cane but greatest profit per acre or per dollar invested.

To secure the maximum profit per acre is the aim of the sugar cane agriculturists of Hawaii. The mathematical analysis of costs and profits based on the yield equation aids in attaining this goal. The profit per acre is the value of cane per acre less the total cost per acre, and it is very simple to find under what conditions the profit is greatest.

The total cost of one acre of cane delivered at the mill may be divided into four general classes, namely:

$\$D$ = cost of a lot of fertilizer which affects the yield of cane according to the law of diminishing increments;

$\$F$ = the fixed charge per acre, such as the rent of land;

$\$T$ = charges per ton of cane that vary directly with the tonnage per acre, for instance, the prices paid to the cultivation contractors, the harvesting cost, including transportation charges;

$\$W$ = charges per acre that vary inversely with the tonnage of the crop, such as the cost of weeding.

The cost of irrigation may be classed under D or T, unless the relation of irrigation and the resulting crop be definitely known. The overhead charge may be added to either F or T. The cost of preparing and planting when pro rated to the various crops according to the crop lengths may be handled as the overhead charge. The relation of weeding cost to the tonnage of cane per acre is not yet clearly known, but for the purpose of illustration may be calculated on the assumption that an acre of bare ground would cost $\$G$ to keep weeds down for one crop length, and that cane grown on the area would save the weeding cost at the rate of $\$H$ per ton cane. When $\$G$ is \$30 and $\$H$ is \$0.25, the weeding cost runs as in the following table:

Tons Cane per Acre	Weeding Cost Per Acre per Crop
10	\$27.50
20	25.00
30	22.50
40	20.00
50	17.50
60	15.00
70	12.50
80	10.00
90	7.50
100	5.00
110	2.50
120	0.00

These values were obtained from $\$G - \$H \times$ tonnage.

If X lots of fertilizer or water, the cost of which is classed under D, results in Y tons of cane per acre, then the total cost of a crop of Y tons per acre is

$$\$DX + \$F + \$TY + \$G - \$HY.$$

Now, if the value of one ton of cane at the mill be $\$V$, then the total value of cane from one acre is $\$VY$. The profit per acre is the value less the cost, or

$$\$VY - (\$DX + \$F + \$TY + \$G - \$HY).$$

This profit is the maximum when X is equal to

$$\frac{1}{\log R} \times \log\left(\frac{-D}{2.302585\,(V + H - T)\,A \log R}\right)$$

in which the numerical values of A and R are to be obtained from the yield equation based on the actual experiments on the area. It is noticeable that $\$F$, the fixed charges, and $\$G$, another fixed charge, have disappeared from the formula. The disappearance has some significance in that the so-called point of maximum profit per acre may be the point of least loss under some conditions.

A numerical example is worked to test the validity of the formula. The field is the one in which Lihue Plantation Company, Experiment 5, 1924 crop, was formerly, and the cultural conditions are supposed to be the same as at the time of the experiment. The yield equation obtained is $Y = 61.645 - 34.351 (0.6341)^{x}$ in which $A = 34.351$ and $R = 0.6341$. Other values assigned are:

$\$D = \$18$ per lot of fertilizers;
$\$F = \$40$ an acre;
$\$T = \$1.50$ per ton cane;
$\$G = \$30$ per acre
$\$H = \$0.25$ per ton cane;
$\$V = \$4$ per ton cane;
$X =$ number of lots of fertilizer of 75 pounds of nitrogen each.

The above figures are not intended to represent actual conditions; they are taken to illustrate the application of the formula.

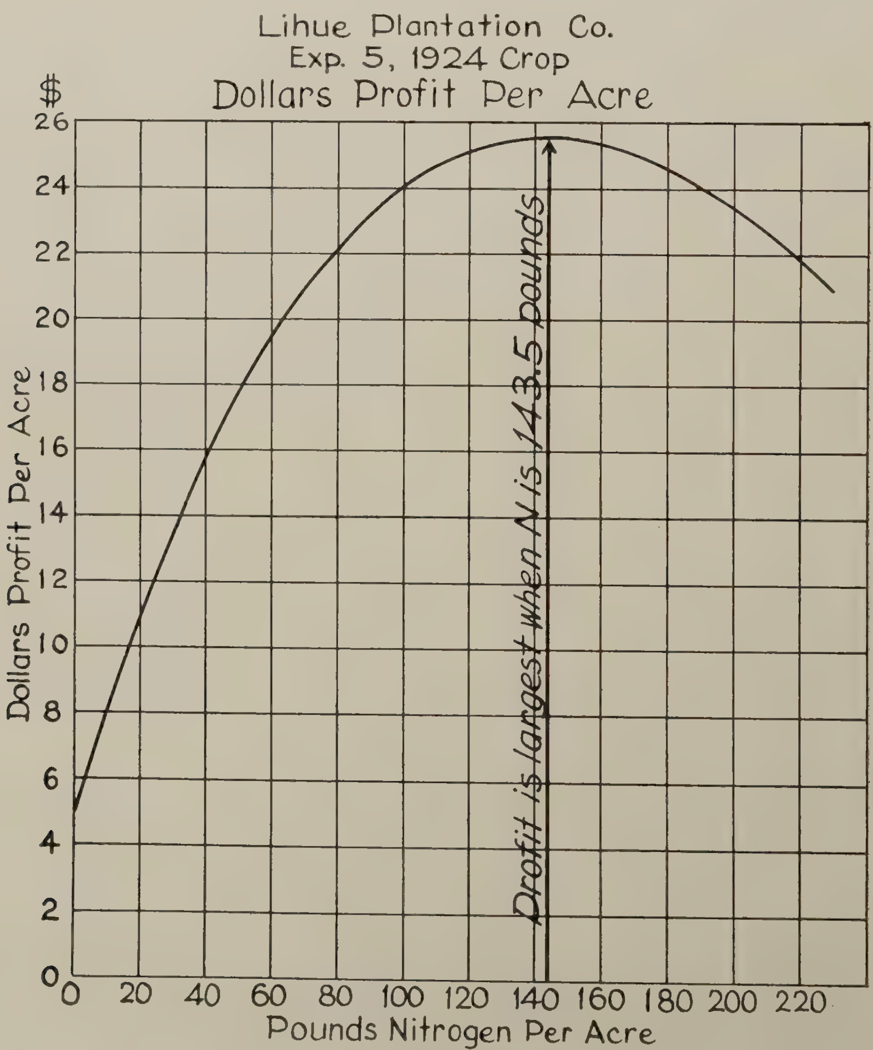

Fig. 4

By substituting these values in the formula and by carrying out the arithmetical operations, indicated, the answer is found in number of lots of fertilizer necessary to secure the maximum profit per acre.

$$X = \frac{1}{\log 0.6341} \times \log \left(\frac{-18}{2.302585\ (4 + 0.25 - 1.50)\ 34.351 \log 0.6341} \right)$$

$$= \frac{\log 0.41827}{\log 0.6341}$$

$$= 1.9134 \text{ lots.}$$

Since each lot is known to be 75 pounds nitrogen, the total amount of nitrogen to apply is 75 x 1.9134 or 143.5 pounds per acre. That 144 pounds is the best amount of nitrogen to use when the maximum profit per acre is sought is brought out in Fig. 4, and also in the following table.

The above amount of 144 pounds of nitrogen would not apply to Lihue at the present time. The experiment was with Caledonia cane, not now planted. With present varieties this figure would be higher.

Pounds Nitrogen per Acre	Tons Cane per Acre	Gross Income per Acre	Cost of Nitrogen per Acre	Fixed Charge per Acre	Tonnage Cost per Acre	Weeding Cost per Acre	Total Cost per Acre	Profit per Acre
X	Y	$\$VY$	$\$DX$	$\$F$	$\$TY$	$\$G—\$HY$		
0	27.278	$109.112	$ 0	$40	$40.917	$23.180	$104.097	$ 5.015
10	39.302	117.208	2.40	40	43.953	22.674	109.027	8.181
20	31.207	124.828	4.80	40	46.811	22.198	113.809	11.019
30	33.000	132.000	7.20	40	49.500	21.750	118.450	13.550
40	34.688	138.752	9.60	40	52.032	21.328	122.960	15.792
50	36.276	145.104	12.00	40	54.414	20.931	127.345	17.759
60	37.770	151.080	14.40	40	56.655	20.557	131.612	19.468
70	39.171	156.684	16.80	40	58.757	20.207	135.764	20.920
80	40.499	161.996	19.20	40	60.749	19.875	139.824	22.172
90	41.744	166.976	21.60	40	62.616	19.564	143.780	23.196
100	42.916	171.664	24.00	40	64.374	19.271	147.645	24.019
110	44.019	176.076	26.40	40	66.029	18.995	151.424	24.652
120	45.057	180.228	28.80	40	67.586	18.736	155.122	25.106
130	46.034	184.136	31.20	40	69.051	18.491	158.742	25.394
140	46.953	187.812	33.60	40	70.430	18.262	162.292	25.520
Point of Highest Profit Occurs Here								
150	47.818	191.272	36.00	40	71.727	18.045	165.772	25.500
160	48.632	194.528	38.40	40	72.948	17.842	169.190	25.338
170	49.398	197.592	40.80	40	74.097	17.650	172.547	25.045
180	50.119	200.476	43.20	40	75.179	17.470	175.849	24.627
190	50.797	203.188	45.60	40	76.196	17.301	179.097	24.091
200	51.435	205.740	48.00	40	77.153	17.141	182.294	23.446
210	52.036	208.144	50.40	40	78.054	16.991	185.445	22.699
220	52.602	210.408	52.80	40	78.903	16.849	188.552	21.856
230	53.134	212.536	55.20	40	79.701	16.716	191.617	20.919

It is to be noted that the maximum profit is between 140 and 150 pounds of nitrogen and is nearer 140 pounds. The formula gives it to be 143.5 pounds. It pays to borrow money from a bank if the working capital be insufficient to handle each acre to its point of maximum profit, provided the rate of interest be lower than the profit for the duration of the crop.

When, however, it so happens that the working capital is limited, then it behooves the one in charge of the plantation to seek the greatest profit for each dollar invested in the crop. The process of arriving at this point is simple. The formulae used are:

$$\text{Let } L = \left(F + G - \frac{D}{2.302585 \log R} \right) \frac{2.302585\, A \log R}{-DM} + \left(\frac{2.302585\, A \log R}{-M} \right) X$$

and $U = \left(\frac{1}{R} \right)^{x}.$

The meaning of F, G, D, R, A and X are the same as used in the foregoing examples. M is the first number after the equality sign in yield equation, $Y = M - AR^{x}$. The yield equation of Lihue Plantation Company, Experiment 5, 1924 crop, is $Y = 61.645 - 34{,}351\ (0.6341)^{x}$ as was given previously, hence, $M = 61.645$. Inserting the proper values for the terms in the formula, the following results:

$$L = \left(40 + 30 - \frac{18}{2.302585 \log 0.6341} \right) \left(\frac{2.302585 \times 34.351 \log 0.6341}{-18 \times 61.645} \right) +$$

$$\left(\frac{2.302585 \text{ x } 34.351 \log 0.6341}{-61.645} \right) X$$

$$= 1.544852 + 0.2539185X.$$

This is a straight line and two points only are needed to determine the line.

$$U = \left(\frac{1}{R} \right)^{x}$$

$$= 1.57704^{x}.$$

which is a curved line, hence many points must be worked out to obtain accuracy.

The values of X tried	L	U
1.37	1.8927	1.8666
1.38	.....	1.8751
1.39	.....	1.8837
1.40	.....	1.8922
1.41	.....	1.9009
1.42	.....	1.9096
1.43	.....	1.9183
1.44	.....	1.9270
1.45	1.9130	1.9358

These values are plotted on cross-section paper, the lines L and U intersect at $X = 1.413$, which shows that the maximum profit per dollar invested in the crop is obtained when 1.413 lots of fertilizer, or in this case $75 \times 1.413 = 106$ pounds of nitrogen, are used. Fig. 5 presents the method of plotting. The following table bears this out. The figures are taken from the previous table.

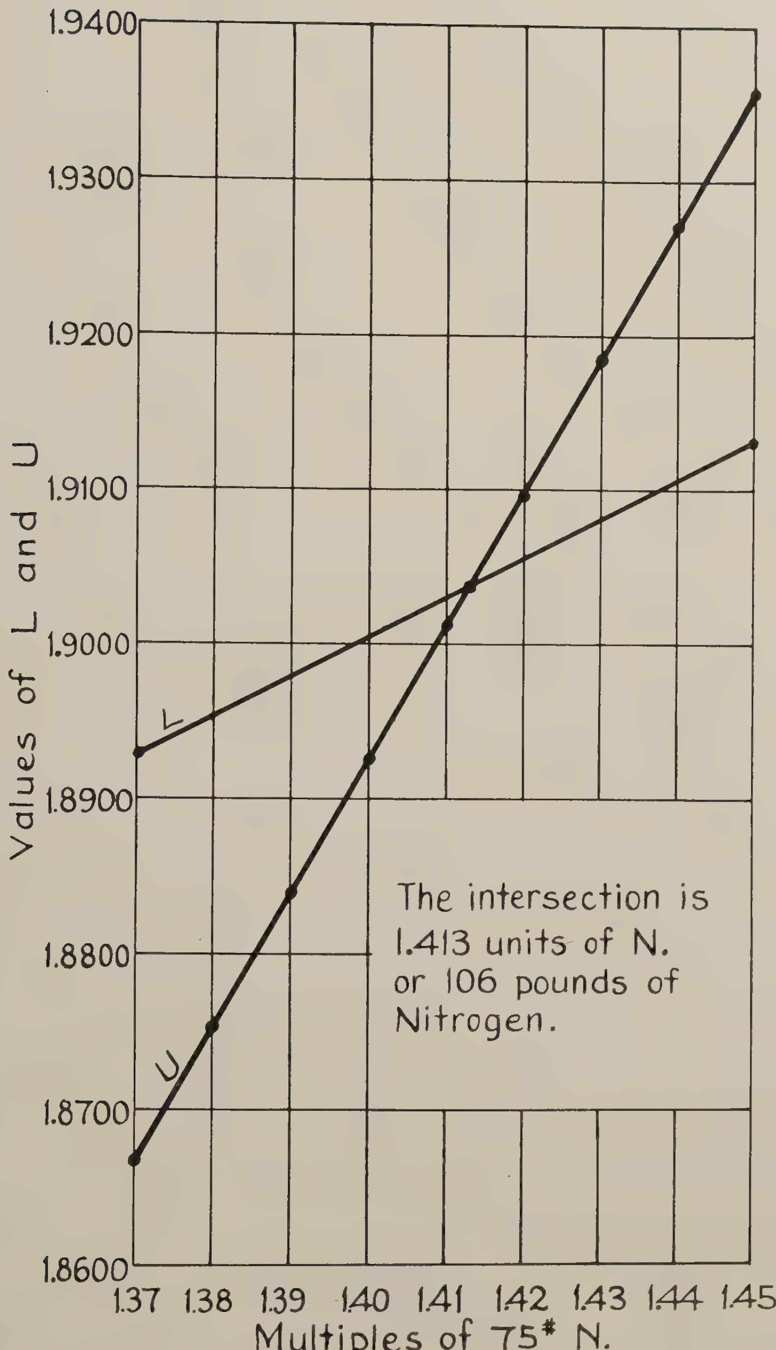
1.9400
1.9300
1.9200
1.9100
1.9000
1.8900
1.8800
1.8700
1.8600
Values of L and U
L
U
The intersection is
1.413 units of N.
or 106 pounds of
Nitrogen.
1.37 1.38 1.39 1.40 1.41 1.42 1.43 1.44 1.45
Multiples of 75* N.

Fig. 5

Pounds N per acre	Profit per acre	Total Cost per acre	% Profit on cost
0	$ 5.015	$104.097	4.818
10	8.181	109.027	7.505
20	11.019	113.809	9.682
30	13.550	118.450	11.439
40	15.792	122.960	12.843
50	17.759	127.345	13.946
60	19.468	131.612	14.792
70	20.920	135.764	15.409
80	22.172	139.824	15.857
90	23.196	143.780	16.133
100	24.019	147.645	16.268
	Point of Highest Profit Occurs Here		
110	24.652	151.424	16.280
120	25.106	155.122	16.185
130	25.394	158.742	15.997
140	25.520	162.292	15.725
150	25.500	165.772	15.383
160	25.338	169.190	14.976
170	25.045	172.547	14.515
180	24.627	175.849	14.005
190	24.091	179.097	13.451
200	23.446	182.294	12.862
210	22.699	185.445	12.240
220	21.856	188.552	11.591
230	20.919	191.617	10.917

The greatest profit is between 100 and 110 and is nearer 110. This checks the results obtained by the formulae. Fig. 6 is the graph of the table.

It is interesting to compare the three points determined from the same data in connection with the amount of nitrogen to apply.

Nature of the Maximum	Pounds N per Acre
Maximum limit of fertilization	507
Profit per acre	144
Profit per dollar invested	106

The comparison clearly demonstrates the necessity of defining the meaning of profitable fertilization prior to computing the amount of fertilizer to use. It may even be necessary to charge the milling expenses to the field because the milling expense per ton cane varies somewhat inversely with the amount of cane handled each year.

The yield equation based on the data of one crop is not entirely satisfactory. The field receiving a fertilization heavier than the amount extracted by the crop, will accumulate plant food, especially phosphoric acid and potash, for succeeding crops. On the other hand, the fields fertilized lighter than the amount drawn away, become poorer from crop to crop. This tendency is readily seen in the results of these two experiments:

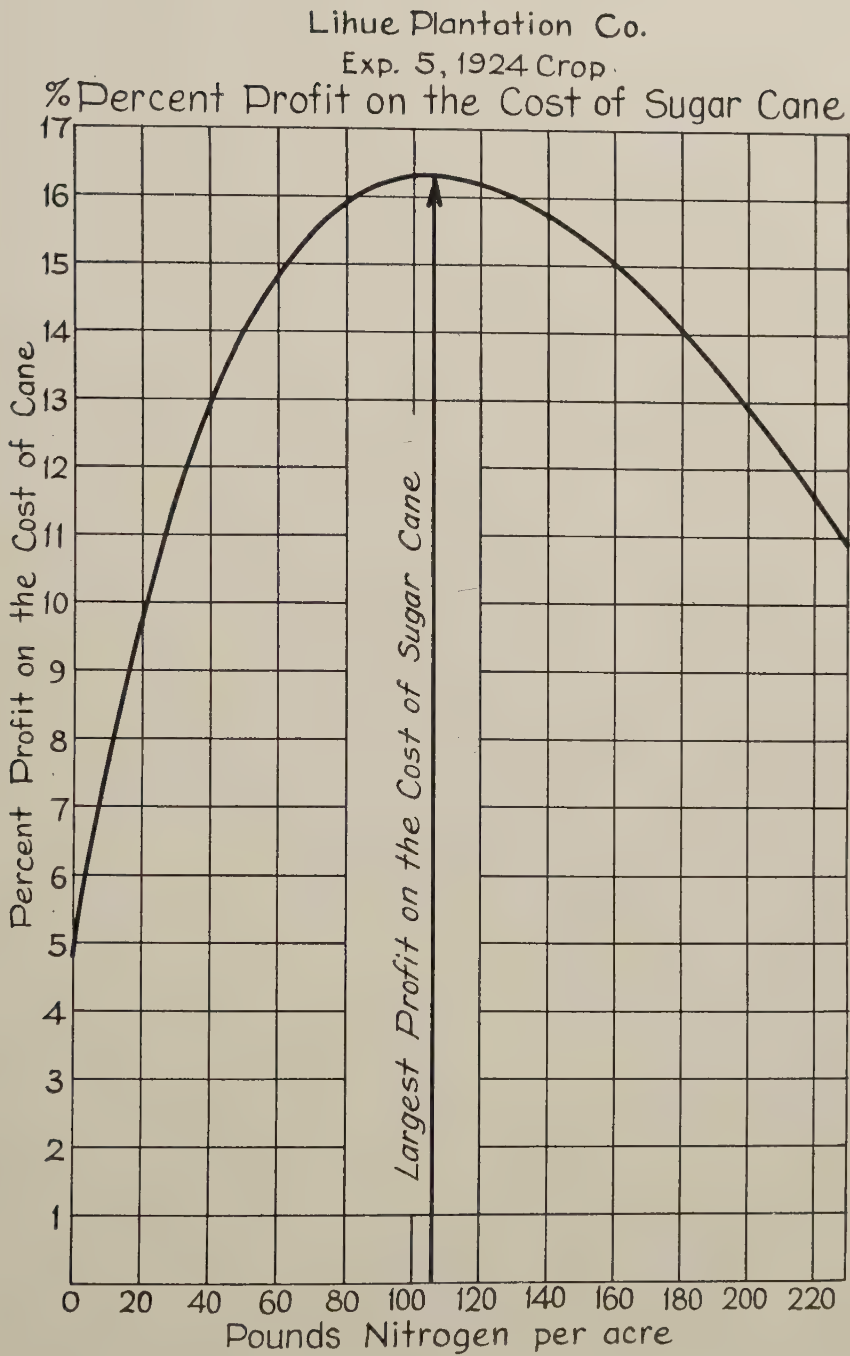
Lihue Plantation Co.
Exp. 5, 1924 Crop
% Percent Profit on the Cost of Sugar Cane
Percent Profit on the Cost of Cane
Largest Profit on the Cost of Sugar Cane
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
20
40
60
80
100
120
140
160
180
200
220
Pounds Nitrogen per acre

Fig. 6

PIONEER MILL COMPANY, EXPERIMENT 2

Pounds Nitrogen per Acre	Tons Cane per Acre 1921 crop		Tons Cane per Acre 1923 crop
0	42.2	>	30.6
100	43.5	>	40.1
150	48.4	=	48.3
200	49.2	<	54.2
250	49.4	<	56.7

LIHUE PLANTATION COMPANY, EXPERIMENT 5

Pounds Nitrogen per Acre	Tons Cane per Acre 1922 crop		Tons Cane per Acre 1924 crop
0	34.4	>	27.3
75	44.1	>	39.8
150	49.8	=	47.9
225	49.5	<	52.9

In both cases the yields of the two successive crops happened to be approximately the same for 150 pounds of nitrogen per acre. Below this amount, the soil seems to be exhausted and above, improved. The quantity of added fertilizer that barely maintains the soil fertility unaltered may be termed maintenance fertilization. In order to maintain our yields, it is vitally necessary to apply at least the maintenance fertilization. The accurate determination of this quantity needs the use of yield equations based on many crop yields corrected for different crop lengths and climate. If the yield curves intersect at approximately a point, the maintenance fertilization can be read off the chart. From this argument, it is logical to conclude that the full effect of fertilization, either light or heavy, cannot be seen in one crop.

The yield equation is applicable to another phase of the soil-fertility question. The measure of soil fertility obtained through this channel is not the absolute quantity of plant food present in the soil but it is rather the measure of the effect of the plant food in the soil in terms of the applied fertilizer. If one ton of mill ash applied to a field affects the cane crop to the same degree as 300 pounds of potash, then the fertility of one ton of mill ash is 300 pounds of potash; yet the mill ash may contain more or less than 300 pounds of potash. In a similar way the soil fertility, S, is expressed from the effect, in terms of the applied fertilizer. The formula is

$$S = \frac{\log A - \log M}{\log R}$$

A numerical example is again cited. Oahu Sugar Company, Experiment 6, 1918 crop, has resolved into a yield curve, $Y = 112.6 - 43.5\ (0.91)^x$ in which

$M = 112.6$
$A = 43.5$
$R = 0.91$

X = lots of 90 pounds per acre of phosphoric acid in the form of reverted. Substituting these values in the formula,

$$S = \frac{\log 43.5 - \log 112.6}{\log 0.91}$$
$$= 8.8 \text{ lots.}$$

The soil in this field contains some plant food, including some phosphoric acid, equivalent, in crop producing power, to $90 \times 8.8 = 792$ pounds of phosphoric acid in the form of reverted phosphate.

The chemical analysis on the samples of soil from this field showed the presence of

0.0019% citrate-soluble P_2O_5
0.184% acid-soluble P_2O_5.

By taking the depth of 3⅓ feet as the average feeding depth of a cane crop, in this type of soil, and the weight of one acre of soil one foot deep as three million pounds, the two kinds of phosphoric acid within the reach of the cane crop are:

0.0019% of 10 million pounds = 190 pounds citrate-soluble phosphoric acid per acre; and

0.184% of 10 million pounds = 18400 pounds of acid-soluble phosphoric acid per acre.

This large amount of phosphoric acid was, in crop-producing power, equivalent to 792 pounds of phosphoric acid from the reverted. The citrate-soluble phosphoric acid in soil is thought to have the same value as phosphoric acid in the reverted form, consequently, $792 - 190 = 602$ pounds of phosphoric acid is accredited to 18,210 pounds of citrate-insoluble phosphoric acid, or, in other words, 18,210 pounds of citrate-insoluble phosphoric acid is equivalent to 602 pounds of phosphoric acid from reverted, a ratio of 100% : 3.31%. The citrate-insoluble phosphoric acid in this field may be said to change into the available form at the rate of 3.31% per crop length.

The above is to be taken as an interesting speculation only and the figure given is not to be taken as actual. This is brought out here to illustrate the many applications of the yield equation. We are starting a number of studies along these lines, and hope, later, to be able to report on the rate of plant food availability in our soils.

The application of yield equations simplifies the experiments dealing with small fertilizer differences. Usually an experiment designed to bring out the effect of a small amount of additional fertilizer does not furnish the desired results due to the unavoidable fluctuations in the fertility of the plots which mask the small differences, and to the small errors that almost always creep in when conducting field experiments. This difficulty can easily be avoided by applying the fertilizer in large steps so that the gain or loss due to the fertilizer is beyond the experimental error, and by interpolating the yield equation for the effect of a small amount of the fertilizer.

Variety comparison also has a close connection with the yield equations. It is well known that a certain variety does better than another under a given fertiliza-

tion, but when the amount of fertilizer is altered the relative values of the varieties also alter or even reverse. A fertilizer test which happened to have two varieties is Oahu Sugar Company, Experiment 3, 1918 crop. The harvesting results demonstrate the point.

Pounds Nitrogen per Acre	Tons Cane per Acre Lahaina		Tons Cane per Acre D 1135
0	57.97	>	55.60
75	65.78	=	65.22
150	70.51	<	72.22
225	71.02	<	76.68
300	74.10	<	78.61
375	75.01	<	84.01

The comparison of yield equations of different varieties eliminates the possible chance of overlooking a cane variety with a peculiar adaptability.

In laying out experiments for the purpose of obtaining yield equations one must endeavor to have one of the fertilizer applications less than the amount needed by the crop, another approximating the general practice, and a third in excess of crop needs; then, as before explained, by interpolating the yield equation the proper amount is quickly determined. Tentative amounts which may be used in various experiments are shown herewith.

When the response to nitrogen is not great, due to other limiting factors, the test could run 60, 120, and 180 pounds of nitrogen, or if the response is likely to be somewhat higher one could use 75, 150, and 225 pounds per acre. For plantations using 200 or more pounds of nitrogen per acre 100, 200 and 300 pounds are suggested.

When there is a question as to whether or not there is need of phosphoric acid, a series of 0, 100 and 200 pounds of P_2O_5 would give the desired information. But when assured of phosphoric acid shortage larger amounts are tried, 100, 200 and 300 pounds per acre.

Potash experiments will be of the same nature except that it may be advisable to use larger amounts of potash in fields low in potash. A series of 125, 250 and 375 pounds per acre would serve.

When it is desired to determine the degree of soil fertility by means of the yield equation it is then necessary to add a series of plots to which no fertilizer is applied.

In testing for any one plant food, it is almost needless to add that one must be sure to supply the other plant foods in sufficient quantity to prevent them from becoming limiting factors.

This brief paper on the use of yield equation has been prepared in order to show the wide application which it has in the study of experimental results.

By its use it is believed that our field experiments may be much simplified and their accuracy greatly increased.

Collection of Formulae *

(1) $Y = M - AR^{x}$

This is the fundamental yield formula of Spillman, in which

Y = yield due to soil fertility and X lots of added fertilizer;
M = the theoretical maximum yield due to soil fertility and the maximum number of lots of added fertilizer or when X becomes infinity;
A = the theoretical maximum yield due to the maximum number of lots of added fertilizer;
R = ratio of two successive increments in the crop and is, by theory, less than one;
X = the number of lots of added fertilizer, and the lots are supposed to be uniform in quantity and quality.

(2a) $\log (Y_{x+1} - Y_{x}) = \log Z = X \log R + \log A\ (1-R).$

The formula is used in evaluating A and R in (1) from the actual harvesting data. The data must have positive increments and the fertilizer must increase by a lot.

Y_{x} is the yield of plot receiving X lots of fertilizer.
Y_{x+1} is the yield of plot receiving $X + 1$ lot of fertilizer.

(2b) $M = \frac{1}{n} (\Sigma\, Y + \Sigma\, AR^{x})$

The value of M is evaluated with this formula.

n = the number of items.

(3a) $A = \dfrac{\Sigma Y \Sigma R^{x} - n \Sigma\, (YR^{x})}{n \Sigma\, (R^{2x}) - (\Sigma\, R^{x})^{2}}$

(3b) $A = \dfrac{n \Sigma\, (YXR^{x}) - \Sigma\, Y \Sigma\, (XR^{x})}{\Sigma\, R^{x}\ \Sigma\, (XR^{x}) - n \Sigma\, (XR^{2x})}$

When some of the increments are negative and the amount of fertilizer added is not increasing by steps of one lot each, these formulae are used to compute A and R. Various likely values of R are tried until the value of A by both formulae (3a) and (3b) become the same. M is evaluated by formula (2b).

(4) $Y = M - A \left(R_{k}^{\frac{m}{k}} \right)^{x}$

The formula is used in changing the lot of fertilizer. In the original equation a lot of fertilizer is k pounds which is changed to m pounds per lot without altering the value of the yield equation.

(5) $Y = M - \frac{A}{R^{d}} (R)^{x}$

The formula moves the zero point of X to the left through the distance of d. When the fertilizer is applied in such a way that the differences between successive amounts is uniform but the initial amount is not a unit dose, the example of such a case is 90, 140, 190, 240, etc., pounds, the initial dose is considered as 0, the successive lots then become 1, 2, 3, etc. The yield curve ob-

* Common logarithm only is used in this article.

tained from the adjusted lots of fertilizer is $Y = M - AR^{x}$. The zero point of X of this curve is in reality $\frac{90}{50} = 1.4$ lots to the right of the natural zero point, hence the zero point of X is moved 1.4 distance back to the left. 1.4 is equal to d in the formula (5).

$$(6)\quad S = \frac{\log A - \log M}{\log R}$$

The S stands for soil fertility expressed in the number of lots of fertilizer tested.

$$(7)\quad Q = -2.302585\, AR^{x} \log R.$$

Q is the slope of the yield equation at X.

$$(8)\quad X = \frac{\log Q - \log(-2.302585\, A \log R)}{\log R}$$

This formula is used in finding the value of X when Q is given.

$$(9)\quad X = \frac{1}{\log R} \times \log\left(\frac{-D}{2.302585\,(V + H - T)\, A \log R}\right)$$

where D = the cost of one lot of fertilizer.
V = the value of a ton of cane at the mill.
H = cost of weeding saved by one ton of cane.
T = per ton cost that varies with the tonnage of cane.

The X in this formula is the number of lots of fertilizer needed to produce the cane crop so as to secure the maximum profit per acre.

$$(10a)\quad \left(F + G - \frac{D}{2.302585 \log R}\right) \times \frac{2.302585\, A \log R}{-DM} + \frac{(2.302585\, A \log R)}{-M} X = L$$

$$(10b)\quad \left(\frac{1}{R}\right)^{x} = U$$

where F = fixed charge per acre per crop length.
G = cost of keeping one acre of bare ground free of weeds for one crop length.
D = the cost of one lot of fertilizer.

The values of L and U are computed with the arbitrary values of X, and the resulting lines are plotted. The value of X at the intersection of the lines is the number of lots of fertilizer to use in order to obtain the highest profit per dollar invested in the crop.

Of these formulae, 4, 5, 6, 7, 8, 10a and 10b have been developed by the agricultural department of the Experiment Station, H. S. P. A., and 1, 2a, 2b, 3a, 3b and 9 are either due to Spillman or modifications of his formulae.

For additional formulae see "The Law of Diminishing Returns" by Spillman and Lang.

Acknowledgment is made to Professor J. S. Donaghho for his kind assistance in verifying the formulae developed by the agricultural department of the Experiment Station, H. S. P. A.

The Influence of Weather on the Production of Sugar in a Typical Unirrigated Plantation of Hawaii

PEPEEKEO SUGAR COMPANY

By U. K. Das

Introduction

The influence of weather on agricultural crops is universally recognized. All of us are familiar with such terms as good and bad weather in relation to particular crops. This influence is more marked in places where the range of variation of the climatic factors is comparatively greater than in places like Hawaii where the climate is equable throughout the year. But even in Hawaii the weather conditions vary from year to year. It is the purpose of the present paper to study the extent to which these variations in weather conditions have affected the sugar crops of Hawaii.

Previous Works

The relation between weather condition and crop yield has been studied in almost every progressive country. Such studies relating to the yield of sugar have begun in a systematic manner only in recent years. However, as far back as 1906, Jorgensen (1) in St. Croix, found an important relation between the yield of sugar and summer rainfall of a year before. His study was of a very general nature. Coming to the recent years, exhaustive studies, employing the statistical methods, have been made by Koenig (2) in Mauritius, Tengwall and Van Der Zyl (3) in Java, and MacDonald (4) in Louisiana. All these studies brought out the fact that weather conditions were greatly responsible for the variation in the yields from year to year.

In Hawaii, the weather has never been studied in its relation to the production of sugar, probably because of the belief that weather conditions in these Islands do not vary considerably from year to year to be of any great significance to the sugar industry, except in the case of pronounced drought or very excessive rainfall. In Hawaii, again, the conditions of sugar production are very different from those obtaining in countries like Java, Louisiana or Mauritius. In these Islands a crop is about two years in producing and includes both plants and ratoons. Again, of the total annual production of these Islands, more than half the amount is made in the irrigated plantations. The progressiveness of the industry tends to make it independent of the vagaries of weather.

The yield of sugar per acre in Hawaii has increased considerably from 8960 pounds in 1905 to 12,740 pounds in 1925, and 13,300 pounds in 1927. This increased yield has no doubt been brought about by a better utilization of our knowledge of the sugar cane plant, of the soil, fertilizers, water, better organization of labor and also more efficient methods of manufacture. However, while maintaining this trend of increasing yield over a period of years, the production of sugar

in the individual years shows great fluctuations. As it is not conceivable that our methods both in the field and the factory change so abruptly from year to year, and to such a great degree, the cause of these fluctuations must be sought somewhere else. In the present paper these annual variations have been analyzed in relation to the variations in the weather conditions in order to discover if there is any definite correlation between weather conditions and yield of sugar per acre.

The annual yields of Pepeekeo Sugar Company have been taken as the subject of study. This has been done for several reasons: (1) Pepeekeo is a typical unirrigated plantation, and as such the influences of both rainfall and temperature on crop yields are likely to be more clearly seen; (2) there has not been any sudden and revolutionary change at Pepeekeo either in the field or in the factory. The land area and the variety of cane grown are about the same in all the years studied.

Pepeekeo Sugar Company is situated on the windward side of the island of Hawaii. The area under any crop is about 2000 acres, and is spread mostly on the slopes of mountains. Yellow Caledonia has been and is still the principal variety of cane. The harvesting season begins in January or February, and continues up to July or August with occasional interruptions caused by extremely unfavorable weather. The harvest includes ratoons and plant canes, and the crop is usually about two years in the field. The cultural practices are about the same as in the other up-to-date plantations, with only one outstanding difference which is that at Pepeekeo all the trash has been returned to the soil since 1905.

NORMAL RAINFALL AND TEMPERATURE
TABLE I

Inches	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Rainfall....	13.39	8.41	14.44	12.03	8.78	7.62	9.18	11.20	11.48	10.16	13.45	12.33	132.47
Temperature F°...	70.1	70.4	70.3	71.2	72.5	73.1	74.3	74.9	75.1	74.5	73.1	71.6	72.5

The average annual precipitation of Pepeekeo for 1905-1925 inclusive is 132 inches and the annual temperature 72.5° F. The average monthly rainfall and temperature for the 21 years are given in Table I, and the same data presented in a graphical form in Chart A. The data have been obtained from the records of the U. S. Weather Bureau Station at Honolulu.

Chart A reveals several interesting points. It is seen that at Pepeekeo, the month of December is warmer than April, that the months of January-March constitute the winter months, and the months of August-October the summer months. Rainfall is generally high in winter and low in summer, but unlike many other plantations there is a general increase of rainfall after the month of June and towards the approach of the warm months of August and September.

The monthly precipitation and temperature for the individual years from 1905 to 1925 are given in Tables II and III. The records are expressed as departures in inches rainfall or degree temperature, the departures being calculated as above (+) or below (—), the average of the 21-year period.

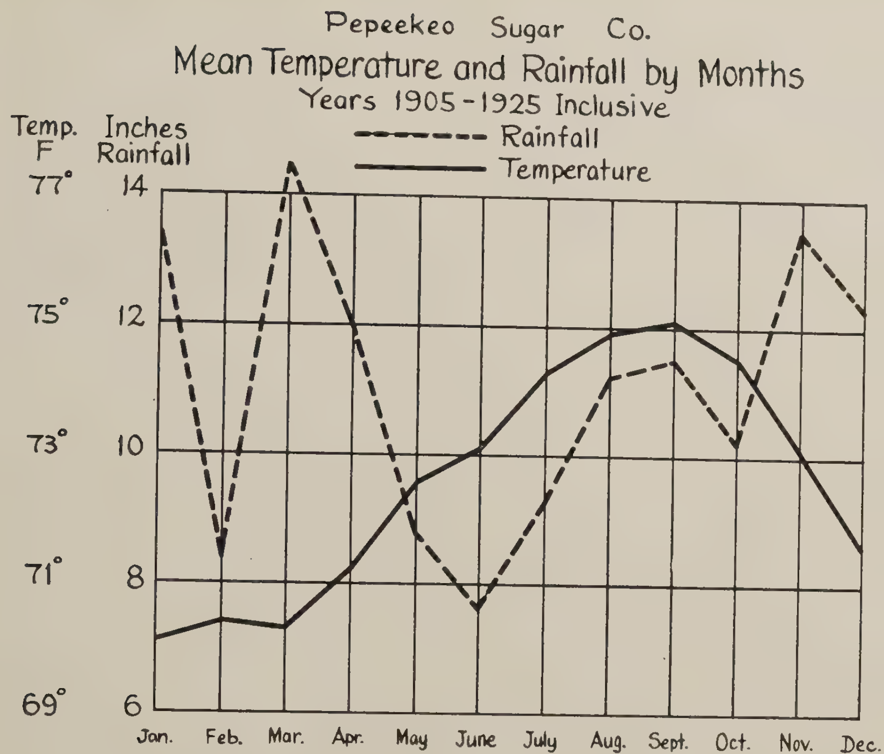

Chart A

TABLE II

TEMPERATURE DEPARTURES

Pepeekeo Sugar Company

ear	January	February	March	April	May	June	July	August	September	October	November	December
905..........	— .7	— .4	+ .2	— .3	— .3	+ .3	+1.3	+1.3	+1.2	+ .4	+ .3	+ .2
906..........	+1.1	+1.0	— .5	+1.0	+ .5	+1.1	+ .9	+ .9	+ .9	+1.3	+1.1	+1.0
907..........	+2.3	+1.2	— .1	0	+1.4	0	+2.6	+1.1	+1.1	+1.1	+ .9	+1.1
908..........	— .1	— .8	+ .9	— .6	+1.1	—1.7	—2.5	—2.3	—1.9	—1.3	+ .8	0
909..........	+1.3	+1.2	+1.0	+ .2	— .8	+ .3	— .5	— .7	— .9	+ .1	+ .8	+ .5
910..........	— .9	— .7	+ .2	—1.0	— .5	— .7	— .6	— .1	+ .5	— .3	+ .1	— .2
911..........	— .4	— .8	+ .2	+ .5	+ .1	+ .1	+ .1	+ .7	— .6	— .2	— .3	— .8
912..........	+ .5	+ .5	—1.5	— .2	— .7	— .2	+ .1	+ .4	+ .5	+ .6	+ .8	— .2
913..........	+ .6	+1.2	+1.3	+ .2	— .1	+ .8	+ .6	+1.3	+ .8	+1.6	+ .3	+ .6
914..........	— .5	+ .1	+ .4	+ .8	— .6	— .3	+ .6	+ .5	+ .3	+ .5	+ .8	— .1
915..........	+ .1	—1.8	+ .6	+ .6	+1.9	+2.1	+1.1	+1.3	+1.6	+ .5	— .5	+ .9
916..........	+1.5	+1.8	+2.2	+1.0	+2.1	+ .3	0	— .7	0	+ .1	— .5	— .1
917..........	— .3	— .2	+ .1	— .1	— .6	— .9	+ .3	+ .7	— .9	—2.5	—2.1	—2.2
918..........	—2.4	—4.2	—3.9	—3.1	—2.9	— .5	—1.1	—1.5	— .9	— .3	—1.2	—2.2
919..........	—2.3	— .4	—1.9	—1.0	—2.0	—1.1	—1.5	—2.1	—1.9	—1.7	—1.9	—1.6
920..........	—1.0	— .8	— .6	— .7	+ .3	—2.5	—3.6	—2.2	—1.7	—2.5	—2.9	—2.8
921..........	—2.2	+1.5	+ .9	0	— .3	+ .3	— .5	—2.3	—2.3	—1.1	+ .7	+ .1
922..........	+ .9	0	+ .1	+ .8	— .7	— .7	+ .3	+ .3	— .3	+ .9	— .7	+1.1
923..........	— .5	—1.3	— .8	— .3	+ .3	+ .5	+ .7	+1.3	+1.7	+1.9	+1.4	+ .5
924..........	+ .5	+ .4	+ .7	+1.6	+ .8	+1.1	+ .5	+ .9	+1.0	+ .6	+1.9	+2.8
925..........	+2.2	+1.6	+ .7	0	+ .8	+ .7	+ .9	+ .8	+1.1	+1.1	+ .9	+2.0
926..........	+2.6	— .5	+ .9	+ .6	+1.0	+1.9	+1.4	+1.1	+ .7	+ .9	+ .9	+ .9
927..........	+ .7	+2.0	+1.3	+1.6	+ .7	+1.9	.....	.....	.....	.....	.....	.....
ormal Tempertures (1905-1906).	70.1	70.4	70.3	71.2	72.5	73.1	74.3	74.9	75.1	74.5	73.1	71.6

TABLE III

RAINFALL DEPARTURES

Pepeekeo Sugar Company

Year	January	February	March	April	May	June	July	August	September	October	November	December
1904	+10.85	+ .18	—13.06	+12.03	— 1.63	—1.33	+ .93	+ 5.12	— 3.16	— 6.37	— 6.66	— 8.01
1905	— 8.96	— 2.53	— 7.26	— 5.03	— .43	— .86	+ .17	+ 1.43	+ 2.81	— .72	+11.19	— 1.46
1906	— 8.86	— 6.64	—10.44	— 5.77	— .92	— .96	— .17	+ 6.23	— 3.35	— 6.32	+ 2.43	+ 1.20
1907	— 7.46	— 4.72	— 3.03	— 5.70	— 3.43	+1.44	+ .58	+17.11	+13.28	+ 4.54	— 3.25	— 7.29
1908	— 6.30	+14.50	— 7.75	+ 2.18	— 3.15	—2.31	— 3.31	— 2.83	+ 1.26	+ .10	— 4.78	+ 1.58
1909	— 6.31	— 2.26	+16.33	+ .45	+ 2.08	—1.98	+ 3.09	— 5.36	— 2.41	— 4.26	—10.42	+ 6.74
1910	+ 6.39	— 3.54	— .53	— 5.48	+ .51	+3.48	— 1.51	+ 2.39	— 7.03	— 2.33	— 2.99	+ 4.68
1911	+ 1.95	+ 4.11	— 2.63	+ .03	+ 7.57	+3.09	— .83	— 3.87	+ 3.42	— 1.53	— 1.32	— 2.73
1912	—12.44	+ 1.67	— 2.69	+ 3.86	— 1.79	+1.19	— 4.08	— 4.03	— 5.92	+ 5.76	— .42	+ 4.84
1913	+18.47	— 2.71	— 8.30	— 2.36	— 1.04	+ .24	— 3.18	— 4.63	— 6.19	— 4.69	+ 6.43	— 2.89
1914	— 4.91	— 3.52	— 5.05	— 3.85	+13.50	+8.30	+10.04	+18.55	+16.07	— 1.96	+ 2.14	— 1.97
1915	— 9.41	— 1.21	—11.70	+ 9.14	— 5.52	+3.09	— .23	— 5.99	— 4.22	+ 3.15	+21.29	+ 2.67
1916	— 2.33	— 7.23	— 4.43	+ .12	+ 9.52	+1.19	— 1.61	+ 1.50	+ 1.14	+ 1.92	— .51	+15.74
1917	+ .65	— 4.40	+ 6.02	+ .64	— .29	+ .21	— 3.18	— 7.14	— 7.52	— 7.29	+ 1.59	— 4.73
1918	+ 7.41	+18.36	+ 9.60	+10.95	+ .28	—2.82	+11.76	— 1.63	— 5.33	— 1.81	— 3.25	+ 2.51
1919	— 8.76	— 2.18	— 3.98	— 6.11	— 3.82	—2.41	— 2.91	— 2.05	— 4.61	— 1.18	— 7.93	— 8.77
1920	— 7.91	— 4.26	+ 9.33	— 5.92	— 6.56	—4.13	— 2.43	— 4.67	+ .88	+11.46	— 6.39	— .66
1921	+19.89	— 3.32	— 8.68	— 1.79	— 4.64	—3.37	— .54	— 1.92	— 5.59	+ 2.43	+ 7.35	+ 4.19
1922	+ 9.98	+ 9.24	+20.43	+ .67	— 1.40	—5.31	— 2.76	— 4.10	+ 6.87	— 3.22	+ 5.17	— 8.43
1923	+29.97	— .87	+ 9.27	+10.53	— .35	+ .46	+ 3.12	+ .64	+ 6.47	+ 4.25	— 7.44	+14.70
1924	— 9.19	— 1.39	— 5.80	+ 6.25	— 1.84	—4.34	+ 2.99	— .84	— 3.22	+ 6.76	— 7.12	— 8.73
1925	— 1.91	— 6.20	+11.26	— 2.88	+ 2.62	+ .26	— 4.78	+ 1.20	+ 2.56	— 5.08	— 2.75	—11.19
1926	— 9.11	— 2.47	—12.23	— 8.30	— 2.88	—4.89	— 4.01	+ 4.01	— 2.31	— 4.28	— 8.31	+ .75
1927	— .40	— 5.45	+ 4.81	— 1.04	+ 1.91	—2.39	....	....	....	....	....	....
Normal rainfall (1905-1925)	13.39	8.41	14.44	12.03	8.78	7.62	9.18	11.20	11.48	10.16	13.45	12.33

Sugar Yields at Pepeekeo

In Table IV are given the area harvested, the predominant variety and yield obtained. It will be seen that there is no great fluctuation in the area harvested or the variety of cane grown. The yield of sugar per acre is shown graphically in Chart B for the 20-year period including 1906-1925. The curve shows a general upward trend, but at the same time fluctuates greatly from year to year.

As has been stated before, the increase in yield from 1906-1925 has been brought about by several factors, all of which can be included in the term "progressiveness." It is therefore impossible to compare the yield per acre of 1905 with the yield per acre of 1925 on the basis of absolute figures. To eliminate the influence of this trend of increased sugar production and to bring about clearly the fluctuations from year to year, the yields of the individual years are expressed as departures from a normal.

The study is begun with 1906, because temperature data prior to 1905 are not available. This period of 20 years from 1906-1925 is divided into four groups of five years,—each group consisting of five consecutive years. The yields of the individual years are calculated as departures above or below the average of the 5-year group to which these years belong.

Table V gives the departures calculated in this manner. Chart C is a graphical presentation of the same information.

TABLE IV

AREA AND CANE YIELD

Year	Area in Acres	Predominant Variety	Crop Yield in Lbs. p. a.	Polarization Per Cent Cane
1905	1914	Yellow Caledonia	6,444	.....
1906	1809	"	7,160	.....
1907	1914	"	6,977	13.96
1908	1700	"	8,928	13.45
1909	1886	"	7,288	.....
1910	1986	"	7,061	13.80
1911	2042	"	7,762	13.21
1912	1969	"	8,135	13.23
1913	2013	"	8,894	13.54
1914	1877	"	10,449	13.55
1915	1976	"	12,094	13.05
1916	1861	"	10,044	13.17
1917	1994	"	11,074	13.25
1918	1926	"	8,598	12.57
1919	2004	"	9,069	12.97
1920	1897	"	10,320	12.85
1921	2001	"	10,420	12.15
1922	1921	"	10,505	11.70
1923	1977	"	9,650	12.37
1924	1850	"	11,758	12.70
1925	2065	"	13,788	12.21
1926	1877	"	13,480	12.45
1927	.....	..	.....	11.29*

* Figures to August only.

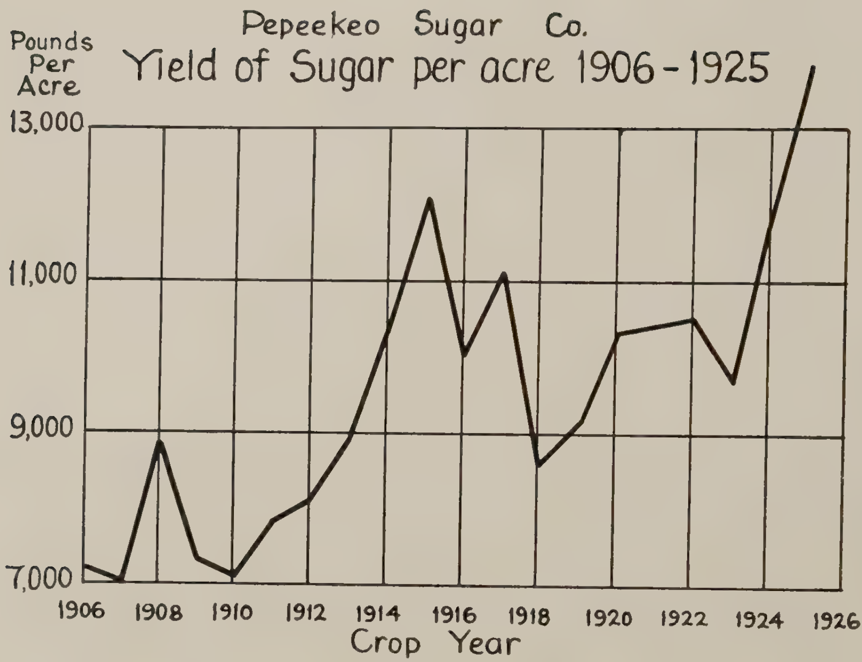

Chart B

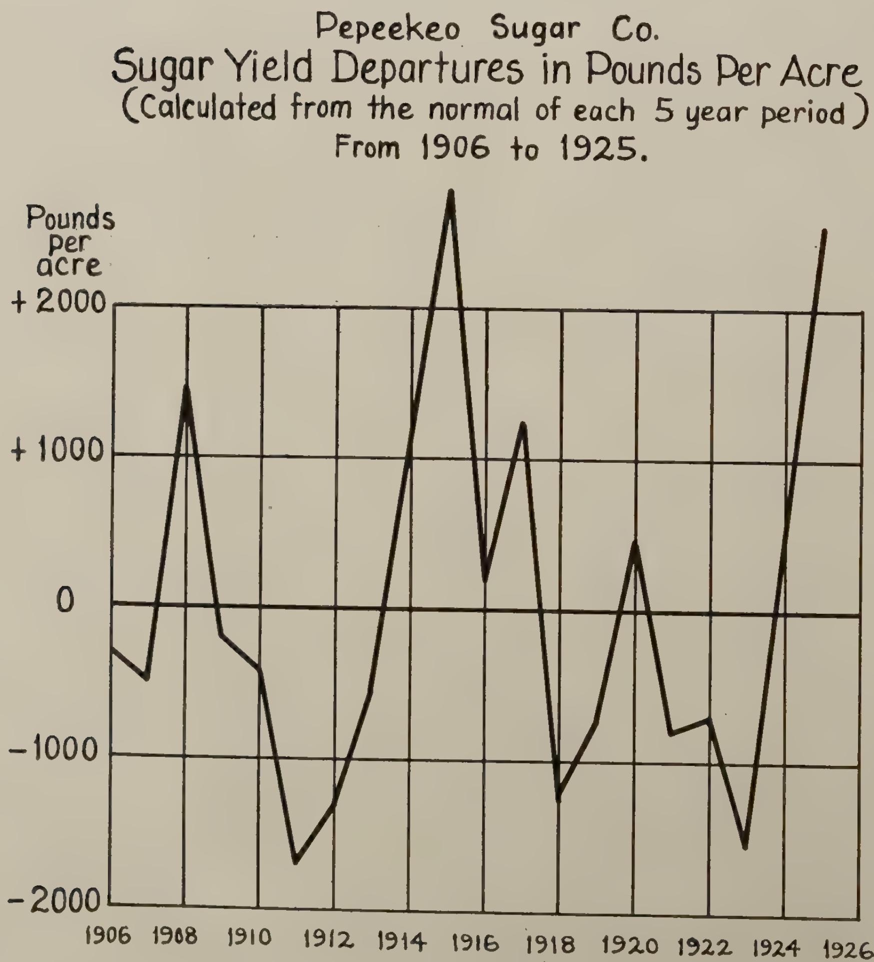

Chart C

TABLE V

SUGAR YIELD DEPARTURES

Year	Sugar Yield in Lbs. p. a.	Average of 5 Years, Lbs. p. a.	Departures, Lbs. p. a.
1906	7,160		— 323
1907	6,977		— 506
1908	8,928	7,483	+1445
1909	7,288		— 195
1910	7,061		— 422
1911	7,762		—1705
1912	8,135		—1332
1913	8,894	9,467	— 573
1914	10,449		+ 982
1915	12,094		+2627
1916	10,044		+ 223
1917	11,074		+1253
1918	8,598	9,821	—1223
1919	9,069		— 752
1920	10,320		+ 499
1921	10,420		— 804
1922	10,505		— 719
1923	9,650	11,224	—1574
1924	11,758		+ 534
1925	13,788		+2564

TABLE VI

MONTHLY RAINFALL AND TEMPERATURE FOR HIGH YIELD AND LOW YIELD YEARS

		Inches	Rainfall	Degrees Temperature	
		High Yield Years (1908, 15, 17, 25)	Low Yield Years (1911, 12, 18, 23)	High Yield Years	Low Yield Years
Two years previous	May	6.82	10.65	73.2	72.6
	June	8.33	7.45	74.3	73.2
	July	9.07	8.99	75.1	73.8
	August	10.26	10.33	76.1	74.0
	September	9.66	8.01	76.4	74.2
	October	9.76	9.60	75.8	74.2
	November	19.13	11.81	73.7	73.4
	December	16.25	20.17	72.4	71.7
Previous year	January	7.42	18.13	71.1	69.9
	February	6.48	9.76	71.5	70.0
	March	9.86	20.26	71.1	70.5
	April	11.24	11.00	72.1	71.3
	May	13.22	10.36	73.4	72.1
	June	9.27	7.99	73.5	72.6
	July	12.13	7.11	75.5	74.3
	August	20.28	8.02	75.4	75.3
	September	18.45	10.42	75.9	74.8
	October	12.98	6.57	75.0	74.0
	November	11.27	14.06	73.9	72.4
	December	11.77	9.53	72.5	71.1

Crop year	January	9.15	20.11	70.6	69.4
	February	9.08	14.23	70.1	69.0
	March	13.90	17.83	70.9	68.8
	April	14.30	18.37	71.2	70.4
	May	7.20	10.21	73.3	71.7
	June	7.93	9.51	73.2	73.1
	July				

High Yield and Low Yield Years

It is seen from Table V and Chart C that the four years, 1908, 1915, 1917 and 1925, have been very good, yielding more than 1000 pounds sugar per acre than the average of the group, and the four years, 1911, 1912, 1918 and 1923, have been unusually poor, yielding less than the average of the group by more than 1000 pounds per acre. These two groups of high yield and low yield years have been analyzed as to the weather conditions prevailing during the growing period. As the crop is usually two years old, the average monthly temperature and rainfall data have been obtained for the entire period of two years and even longer. In Table VI are given the average monthly temperatures and rainfall obtaining during the growing period of the two groups of years. In Charts D and E the same data are shown by curves.

A study of Chart D shows that for the high yield group of years the temperature has been consistently higher than the temperature of the corresponding months in the low yield group. This is true not of one month, but every single month in the two-year period—an information of unusual interest. The greatest difference

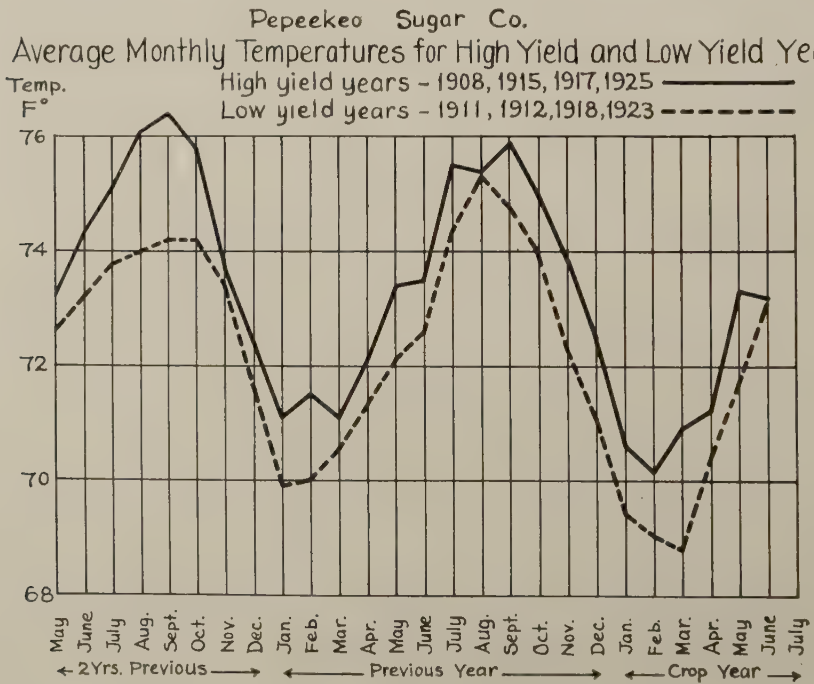

Chart D

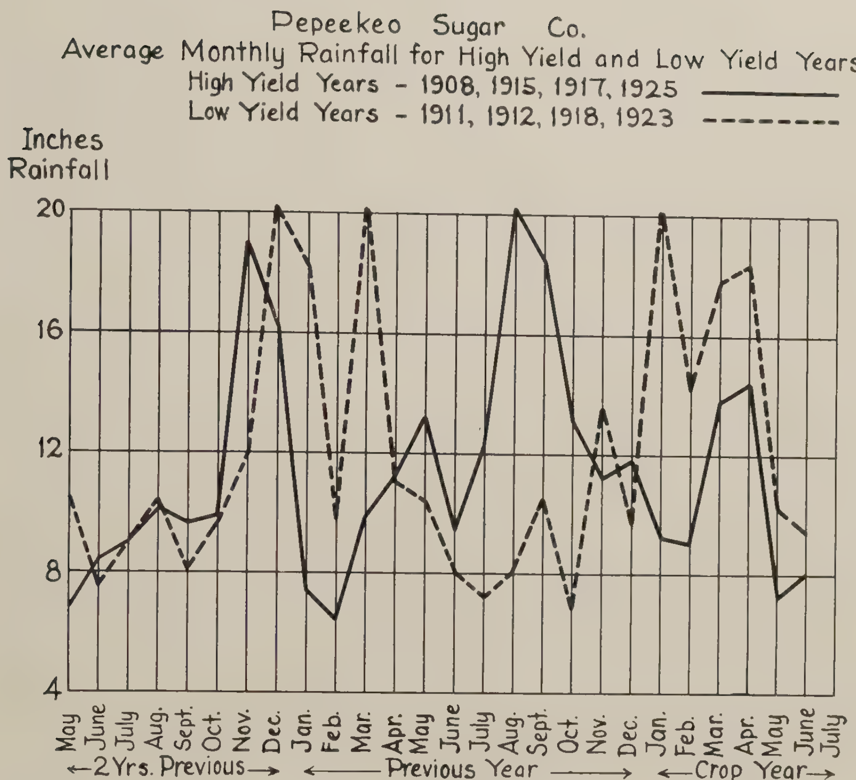

Chart E

does not, however, come either in the crop year or the year previous, but in the warm months of August, September and October, two years previous. This fact is of great significance, because it seems to indicate the good effects of warm conditions in the early stages of the cane crop. It will be remembered that at Pepeekeo the harvest begins towards the end of January and ends in August; therefore, the ratoons as well as the plant cane are all young in the months of August, September and October.

A study of Chart E reveals the fact that the high yield years have had exceptionally well distributed rainfall, while in the low yield years the rains came when they were least desired.

We have noticed that at Pepeekeo rainfall is very high in the cold winter months of January and March. Against an average temperature of 70.5° F. in January and March, we have a rainfall of about 14 inches per month. When the cane is very young this high rainfall, together with the cold temperature, is likely to produce a wet and damp condition injurious to the health and activity of plants.

In the months of January and March of the previous year, the poor yield years have unusually high rainfall, more than 20 inches per month against a rainfall of about 7 inches per month in the corresponding period of the good yield years, while temperatures for these months have been lower in the poor yield years than the temperature in the same months in the good yield years.

In the months of May to October, inclusive, of the previous year, the good yield group have a much higher rainfall than in the corresponding months in the low yield group. The usually warmest month of August has more than 20 inches of rain in the good yield group, and only 7 inches in the same month of the poor yield group.

In the ripening and harvesting season beginning from January of the crop year, the good yield years, as is to be expected, have a much lower rainfall than in the corresponding months of the poor yield years.

Thus we see that the conditions of temperature and rainfall in the good yield years have been exactly what we would have ourselves prescribed if we had control over these two weather factors.

Correlation Studies

In order to bring out more clearly the influence of the different months in the making of a crop, the statistical methods of correlation have been employed. For the theory and evolution of these methods the reader is referred to some standard books on statistical methods. An excellent interpretation of these methods is given in Babcock and Clausens' *Genetics in Relation to Agriculture* (published in 1918 by McGraw-Hill Book Company).

If there is any direct and linear correlation between two phenomena, then it is possible to express that correlation by what is known as the "co-efficient of correlation."

Both the magnitude and the sign of this co-efficient are of importance. A perfect correlation, rarely obtained in agricultural operations, is expressed by the highest possible co-efficient, 1.0. If the co-efficient is more than 0.5, then the two variables are believed to be definitely correlated. If the co-efficient lies between 0.3 and 0.5, the correlation is believed to be low, but still of some significance. Co-efficients below 0.3 are regarded to signify doubtful or very low correlation.

If the co-efficient has a + sign preceding it, the variables are positively correlated, i. e., any increase or decrease in one variable will follow an increase or decrease in the other variable. If the sign is —, then the variables have a negative or opposite correlation.

In the study of agricultural crops the co-efficient of 0.5 or more is believed to be of "critical" significance. That is, if it is found that the temperature or rainfall at any period has a co-efficient of correlation of 0.5 or more, then that period is regarded to be of critical importance to the crop. The good or bad conditions in that period are likely to leave a permanent stamp on the crop correlated.

The method of finding the co-efficient is the one used by Babcock and Clausen in their *Genetics in Relation to Agriculture,* referred to previously. An illustration is given in Table VII. The co-efficient of correlation has been worked out for temperature in the month of August and sugar yield in the crop year two years following:

TABLE VII

Calculation of Co-efficients of Correlation Between Temperature Departures in the Month of August and Sugar Yield Departures for the Crop Harvested Two Years Later.

Sugar yield departures (in Hundred lbs.) ⟶ x

Temperature departures ⟶ y

y \ x	-20	-16	-12	-8	-4	0	4	8	12	16	20	24	28	fy	d'y	fd'y	fd'²y	Σd'xd'y
3																		
2				1	1				1			2		5	+1	5	5	88
1				2		1	1	1	1					6	0	0	0	0
0		2												2	-1	-2	2	16
-1	1						1							2	-2	-4	8	0
-2		1		3										4	-3	-12	36	24
-3																		
fx	1	3	0	6	1	1	2	1	2	0	0	2		19		$-\frac{13}{19}$	$\frac{51}{19}$	$\frac{128}{19}$
d'x	-12	-8	-4	0	4	8	12	16	20	24	28	32						
fd'x	-12	-24	0	0	4	8	24	16	40	0	0	64						
fd'²x	144	192	0	0	16	64	288	256	800	0	0	2048						

wy = -.68
w²y = .46

$\frac{120}{19}$ = wx = 6.32
w²x = 39.94

$\frac{3808}{19}$ = 200.42
39.94
160.48
δx = 12.67

= 2.68
.46
2.22
δy = $\sqrt{2.22}$ = 1.49

= 6.74
wxwy = -4.29
11.03

δxδy = 18.88

r = $\frac{11.03}{18.88}$ = +.58

Co-efficient of Correlation (r) = +.58

TABLE VIII

CO-EFFICIENTS OF CORRELATION BETWEEN TEMPERATURE, RAINFALL AND SUGAR YIELD

	Months	Mean Temperature and Sugar Yield	Rainfall and Sugar Yield	Maximum Temperature and Sugar Yield
Two years ago	May	—.04	—.08	.09
	June	+.32	.19	.40
	July	.32	.12	.51
	August	.58	.01	.38
	September	.53	.03	.54
	October	.50	.01	.49
	November	.29	.26	.13
	December	.34	—.01	.10
One year ago	January	.23	—.14	.24
	February	.32	—.28	.33
	March	.18	—.38	.20
	April	.37	.04	.31
	May	.29	.26	.16
	June	.23	.11	.07
	July	.26	.34	.21
	August	.22	.55	.19
	September	.35	.43	.13
	October	.42	.36	.21
	November	.35	—.10	.29
	December	.37	—.03	.38

Crop year	January	.32	—.42	.24
	February	.13	—.29	.14
	March	.36	—.02	.44
	April	.29	—.08	.41
	May	.40	—.07	.47
	June	.27	.07	.16

The crop yields for the years 1906-1925 have been correlated in the manner shown above for every month and for both the weather factors, namely, temperature and rainfall. The co-efficients are given in Table VIII, and represented graphically in Chart F.

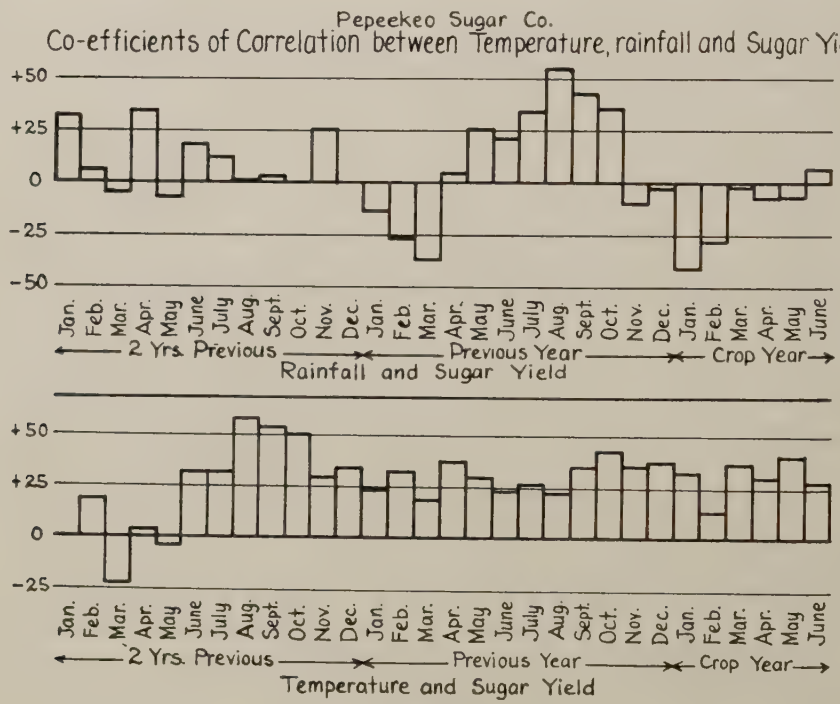

Chart F

Temperature and Crop Yield

It is seen, and as has already been suggested by Chart D, that temperature has a significant positive correlation throughout the entire crop period. For every month beginning in April, two years previous, any increase in temperature over normal tends to increase the production of sugar per acre. In other words, at Pepeekeo warm temperature in relation to a particular crop is always beneficial no matter when it comes.

There are also found to be three critical periods so far as temperature is concerned. These are the months of August, September and October, two years previous. Thus, for the crop of 1925, the months of August-October, of 1923, will be of "critical" value. This should not cause surprise. These months seem

to be so removed from the actual harvest time that on a cursory examination we are not likely to attach much importance to these. However, as an eminent English meteorologist has said, in connection with the agricultural crops of England, we are likely to "credit the plants with too short memories." But a crop "never forgets and hardly ever forgives the treatment which it has received" in a previous season. As we have stated before, the months of August, September and October, two years previous, in relation to a particular crop, happen to be the months when the cane is young and the rate of growth is active. A good temperature means a good, early start; and good growing conditions during the early and formative period are always of great importance not only to the cane plant but also to all living organisms.

Rainfall and Crop Yield

When we come to study the co-efficients of correlation between monthly rainfall and crop yield, we find that our conclusions derived from Chart E are fully justified.

The winter months of January, February and March, of the previous year, have a negative correlation, i. e., high rainfall lowers the yield. The summer months have a positive correlation and negative correlation is again evidenced in the ripening and harvesting season.

Therefore, for an ideal distribution of rainfall, we must have low rainfall in the winter months of December-March, and high rainfall in the summer months of the previous year, and low rainfall again in the ripening and harvesting months of the crop year. This ideal is realized in the case of high yield years as we have already seen.

For rainfall, there is only one month which is of "critical" importance. It is the month of August—usually the warmest month—of the previous year. That high rainfall in a period of high temperature will increase growth and permanently influence the crop yield is evident on the very face of it.

Maximum Temperature and Crop Yield

Koenig (2) has found that in Mauritius the sugar yield appears to have a better correlation with maximum temperature than with mean temperature. To find out if such a condition exists at Pepeekeo, the sugar yields have been correlated with monthly maximum temperature. The co-efficients are given in Table VIII. It is seen that monthly maximum temperature has about as great a significance as monthly mean temperature. All of which tends to accentuate the importance of high temperature at Pepeekeo to the production of high yields. The co-efficients are not, however, of any greater significance than those obtained from mean temperature. The mean monthly temperatures at Pepeekeo can therefore be accepted as correct indication of weather conditions.

Total Warmth and Sugar Yield

As has been suggested by the co-efficients of correlation between mean temperature and sugar yield, an increased temperature in any of the 24 months begin-

ning with June, two years previous, and ending with May of the crop year, will enhance, to a certain degree, the yield of sugar. We would, therefore, expect that if we could express quantitatively the total warmth received by any crop, then, we could explain the periods of low and high yield on the basis of the total warmth.

To this end, we have used in this paper a term "day-degree," adopted very widely by the British weather authorities. In our case a day-degree is defined as one degree Fahrenheit temperature above 60° operating for one day. A day having a mean temperature degree of 70° will, therefore, have a value of 10 day-degrees. It is assumed here that cane grows very little or not at all below a daily *mean* temperature of 60° F.

The total day-degrees corresponding to a particular crop year are, therefore, calculated by adding the day-degrees for each month. In Table IX the day-degrees or total warmth corresponding to the crop years are given. In Chart G are plotted the same data.

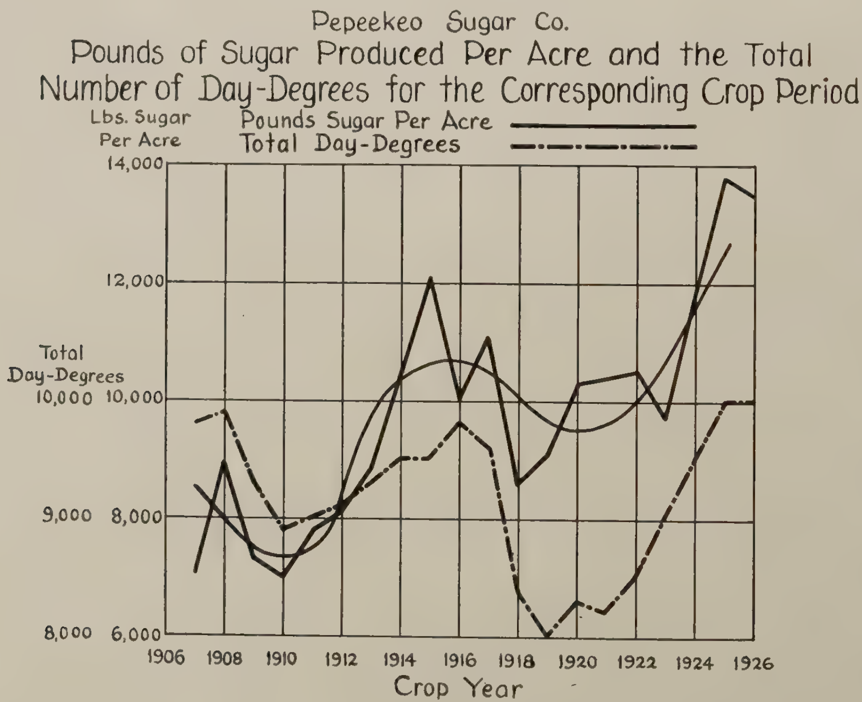

Chart G

TABLE IX

YIELD OF SUGAR PER ACRE AND THE TOTAL NUMBER OF DAY-DEGREES IN THE CORRESPONDING CROP PERIOD

Year	Pounds Sugar per Acre	Total Day-Degrees
1907	6,977	9,818
1908	8,928	9,901
1909	7,288	9,343
1910	7,061	8,916
1911	7,762	9,053
1912	8,135	9,107
1913	8,894	9,312
1914	10,449	9,546
1915	12,094	9,509
1916	10,004	9,795
1917	11,074	9,591
1918	8,598	8,389
1919	9,069	8,004
1920	10,320	8,287
1921	10,420	8,193
1922	10,505	8,513
1923	9,650	9,032
1924	11,758	9,548
1925	13,788	10,027

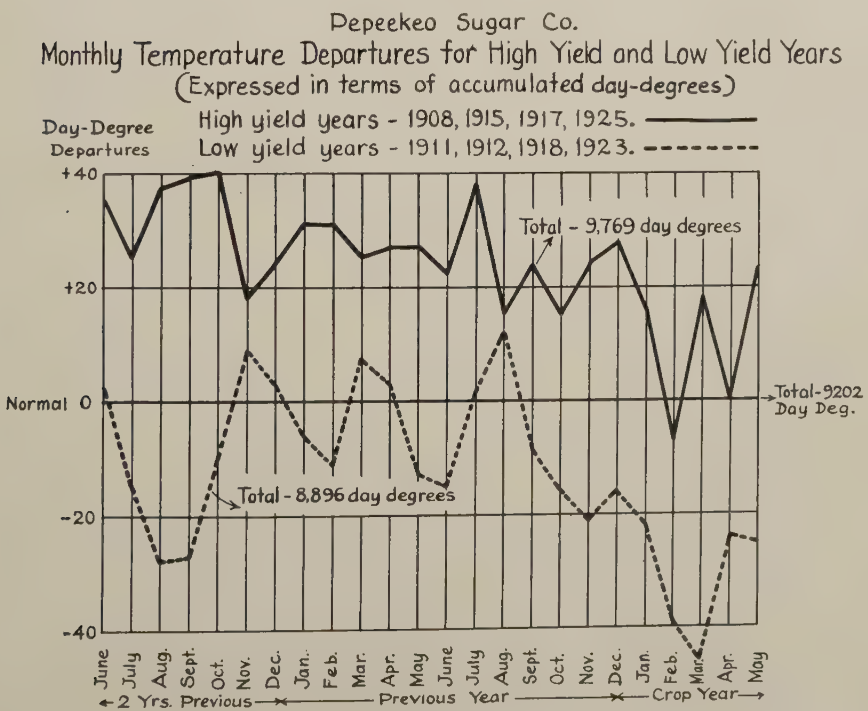

Chart H

As was expected, we find that the total warmth or total number of day-degrees bears a striking relationship to periods of high and low yield. From Chart G we see that the low yield periods from 1908 to 1912 and from 1918 to 1923 correspond with two periods having comparatively low total warmth. The periods of high yield coincide with periods of high total warmth. The relationship is better brought out by studying the smooth curve which represents the trend of sugar yield from 1906-1925.

The normal monthly day-degrees are obtained from the average monthly temperature of the years 1905-1925. If we now take the high yield years at Pepeekeo, namely, the years 1908, 1915, 1917 and 1925, and the low yield years, 1911, 1912, 1918 and 1923, and calculate for every month the day-degrees above or below the normal of the 21 years referred to above, we find a striking result. In Table X are given the day-degree departures above or below the normal for the high and low yield years. The data are represented in Chart H.

TABLE X

DAY-DEGREE DEPARTURES FOR HIGH YEAR YIELD AND LOW YIELD YEARS.
HIGH YIELD YEARS—1908, 1915, 1917 AND 1925.
LOW YIELD YEARS—1911, 1912, 1918 AND 1923.

	Month	Departures: High Yield Years	Departures: Low Yield Years	Normal Day-Degrees
Two years ago	May	21	3	391
	June	36	3	396
	July	25	—15	428
	August	37	—28	434
	September	39	—27	426
	October	40	—10	440
	November	18	9	402
	December	24	3	363
One year ago	January	31	— 6	307
	February	31	—11	280
	March	25	7	326
	April	27	3	339
	May	27	—13	375
	June	22	—15	378
	July	38	0	443
	August	15	12	474
	September	24	— 9	444
	October	15	—16	434
	November	24	—21	372
	December	28	—16	344
Crop year	January	16	—22	291
	February	—8	—39	252
	March	19	—46	273
	April	0	—24	312
	May	24	—25	363
	June	3	0	393
Total		591	—303	9680

It is seen that in the poor yield years the warmth has been usually less than in a normal year, and that in the good yield years the warmth has been greater.

"CRITICAL" PERIODS AND CROP FLUCTUATIONS

We have found that the temperature during the months of August, September and October, two years previous to a crop is of "critical" importance to the crop. Also the rainfall in the month of August, previous year, is of "critical" importance. If, as we have said, these periods leave permanent stamp on the crops, then by studying these periods it should be possible to explain the fluctuation in *yield* and even predict a coming crop.

In Table XI are given the average monthly temperature in the "critical" period mentioned above, and also the amount of rainfall in the "critical" month of August, previous year.

The temperature, rainfall and sugar yield data, are shown by three separate curves in Chart I.

Pepeekeo Sugar Co.

Correlation between average temperature for Aug., Sept., Oct. two years ago, rainfall in August one year ago and yield of sugar.

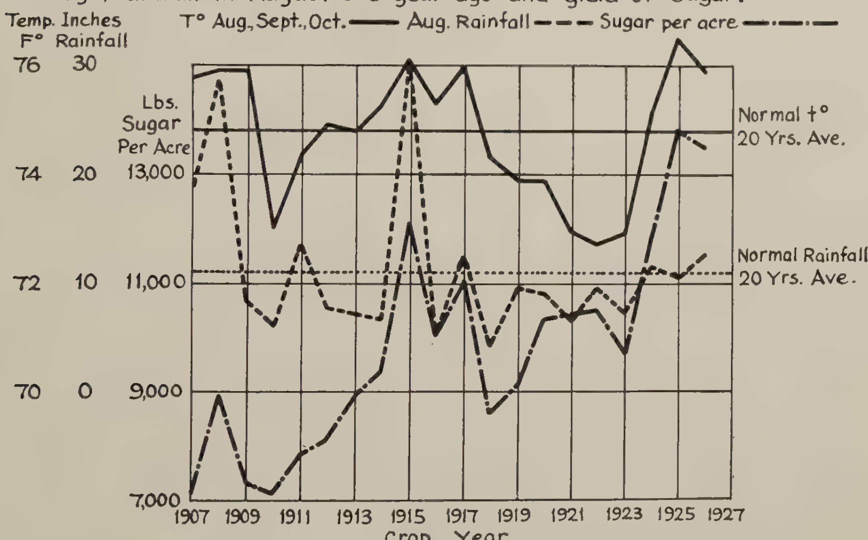

Chart I

It will be noticed that it is possible to explain the fluctuations in the sugar yields at Pepeekeo since 1906 on the basis of the weather conditions during the two "critical" periods—consisting only of four months and not the entire crop period of two years or more.

On the temperature and the rainfall curve we have shown the periodic or monthly normal by straight lines. We see that the period of low yield following 1917 had not only low temperature in the "critical" months, but also rainfall below normal in the critical month of August of the previous year.

By combining the two curves—one of critical temperature and one of critical rainfall, we may actually be able to forecast the crop at Pepeekeo a few months before the grinding starts.

TABLE XI

AVERAGE TEMPERATURE IN THE MONTHS OF AUGUST, SEPTEMBER AND OCTOBER, TWO YEARS PREVIOUS; RAINFALL IN AUGUST, ONE YEAR PREVIOUS, AND THE YIELD OF SUGAR PER ACRE

Year	Lbs. Sugar per Acre	Average Temperature Degrees August-October	Inches Rainfall in August
1907	6,977	75.8	17.43
1908	8,928	75.9	28.31
1909	7,288	75.9	8.37
1910	7,061	73.0	5.84
1911	7,762	74.3	13.59
1912	8,135	74.9	7.33
1913	8,894	74.8	7.17
1914	10,449	75.3	6.57
1915	12,094	76.1	29.75
1916	10,044	75.3	5.21
1917	11,074	76.0	12.70
1918	8,598	74.3	4.06
1919	9,069	73.9	9.57
1920	10,320	73.9	9.15
1921	10,420	72.9	6.53
1922	10,505	72.7	9.28
1923	9,650	72.9	7.10
1924	11,758	75.1	11.84
1925	13,788	76.5	10.36
1926	13,480	75.9	12.40

Recent Record Crops

The years 1924, 1925, and 1926, have all been record years in these Islands. In every one of these years, all previous crop records have been broken. At Pepeekeo, these three years, though not all record years as regards yield per acre, have been exceptionally good years.

In the light of the information obtained previously in this paper, it is possible to explain how far weather has been a contributing factor to these high yields. In Charts J and K we have plotted the average monthly temperature and monthly rainfall for the entire crop period of this group of three years. We have also plotted along with it the normal (average of 1905-1926) monthly temperature and rainfall.

It is seen from Chart J that as regards temperature the years 1924-1925, 1926, have been exceptionally favored. The temperature is higher than the normal throughout the entire crop period.

From Chart K is seen that rainfall, though not ideally distributed, has yet been favorable in the summer months, and during the ripening and harvesting season.

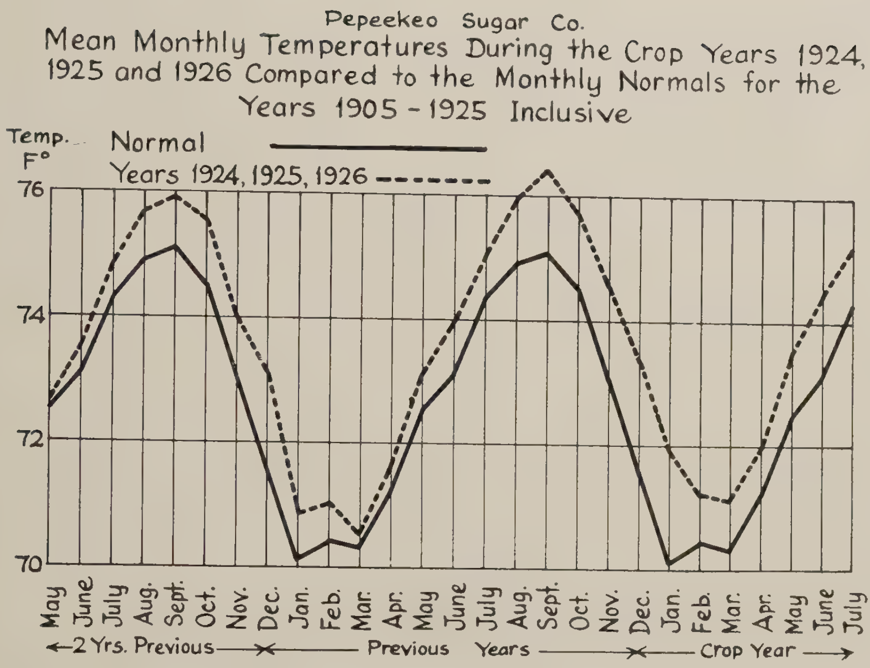

Chart J

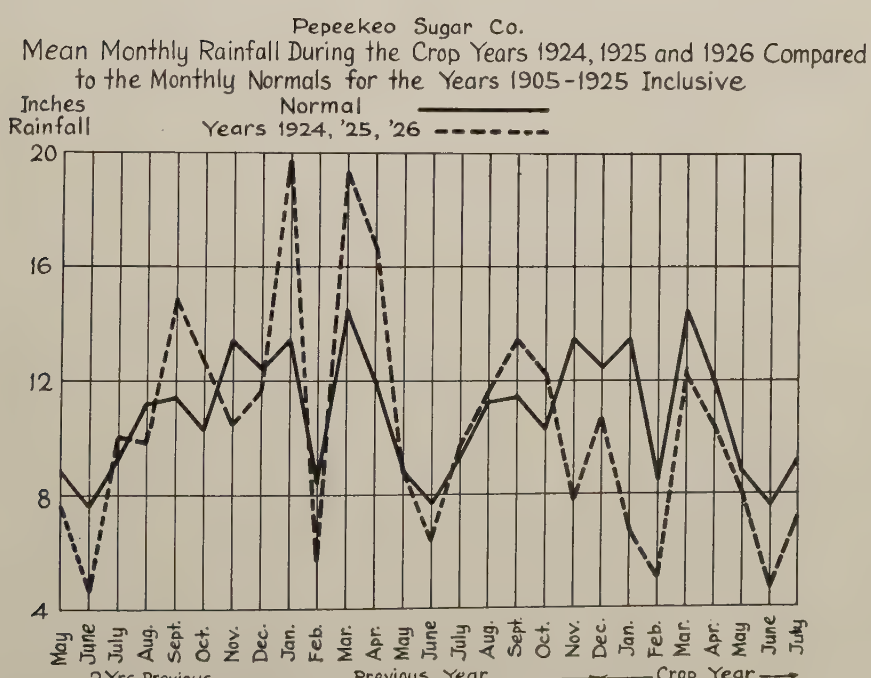

Chart K

Pepeekeo a Typical Unirrigated Plantation

Elsewhere we have mentioned that Pepeekeo is a typical unirrigated plantation. Chart L is brought forward in support of this contention. It is seen from this chart that there is a remarkably close relation between the fluctuations in sugar yield at Pepeekeo and at the average unirrigated plantation.

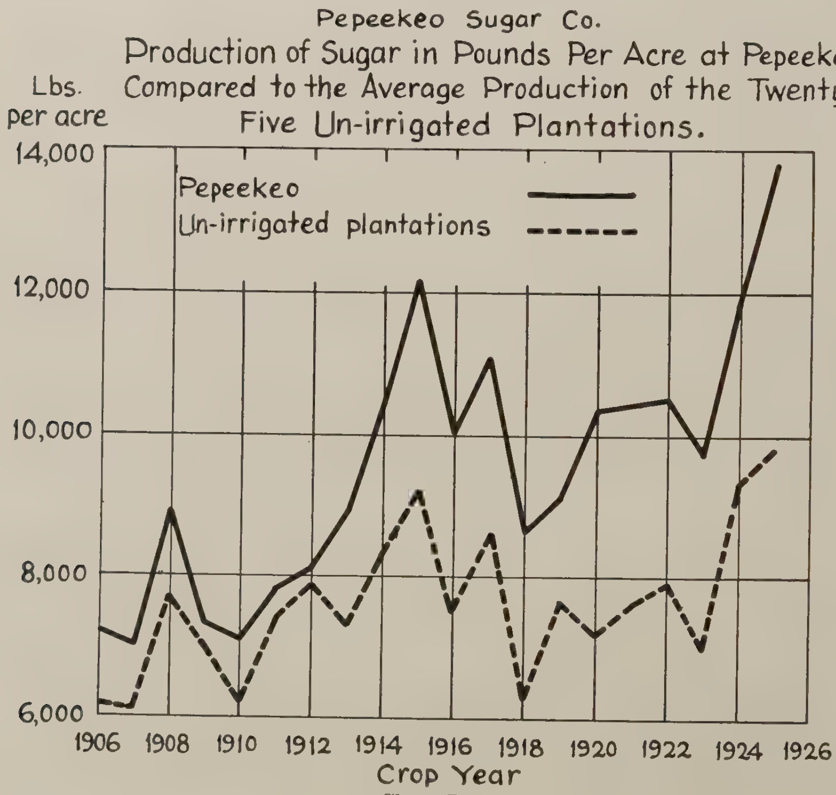

Chart L

This leads us to suggest that the conditions of weather that have been responsible for the fluctuation in yield at Pepeekeo have also been responsible for fluctuations of the same nature at other places. The unirrigated plantations, numbering 25, cultivate 49 per cent of the total area in cane in Hawaii, and produce 36 per cent of the total annual output of sugar in these Islands.

Other information of interest is brought out by Chart L. Up to the year 1912 the average production per acre at Pepeekeo is comparatively close to the average production per acre in all the unirrigated plantations. From 1912 on, the difference in the yield per acre at Pepeekeo and the average yield of all other plantations begins to increase. This increasing difference is very well brought out by the relative rise and drop of the two curves in Chart L.

The conclusion is that at Pepeekeo there have been some factors at work which have accelerated the rate of increase in the production of sugar as compared to the unirrigated plantations as a whole. In other words, Pepeekeo has progressed more since 1912 than the average unirrigated plantation.

Weather Conditions and Sugar Content of Cane

Here we have taken the figure expressing the polarization per cent cane to represent the total sugar content of cane of any crop year. Polarization per cent cane is based on the concentration of sugar in the mixed juice as well as that in the bagasse.

We propose to consider the effect of weather on the sugar content of the cane only, forgetting for the time being its influence on crop yield.

The yield of sugar depends on two factors, namely, the quantity of the cane and the quality of the cane. Of these two factors, the quantity of cane is of greater importance in most of the cases because of the fact that quantity of cane varies much more greatly than the quality of the cane.

To illustrate the point: At Pepeekeo the greatest variation in the polarization per cent in cane in any two successive years is found to be only 9 per cent between 1926 and 1927. The variation in the quantity of cane obtained is about 20 per cent between 1924 and 1925. Obviously, therefore, in most cases the yield of sugar will follow the yield of cane.

While quality is not the greatest factor in causing fluctuations, it is still of great importance.

The sugar content of cane for any one variety depends on several factors, such as:

(1) Age of cane at the time of harvesting.
(2) Season of planting and harvesting.
(3) Conditions of weather and soil during the period of growth.
(4) Cultural treatments—water, fertilizers applied, etc.
(5) Freedom from disease or other injuries.

Independently of all considerations the sugar content of cane appears to vary inversely as the quantity of cane. A year of high cane yield is likely to be a year of comparatively low sugar content in cane. In Table XII are given the yield of cane in some recent years and the sugar content in cane at Pepeekeo.

TABLE XII

Year	Tons Cane p. a.	% Increase or Decrease Over Previous Year	Polarization in Cane	% Increase or Decrease Over Previous Year
1924........	50.13	....	12.70	...
1925........	60.03	+20	12.21	—4
1926........	57.93	— 4	12.45	+2
1927........	61.84	+ 7	11.29	—9

In Chart M is shown that while the yield of sugar per acre has been progressively increasing, the sugar content of cane has been progressively decreasing. The explanation is that the increases in the yield of sugar have been obtained in spite of the decrease in the quality of juice.

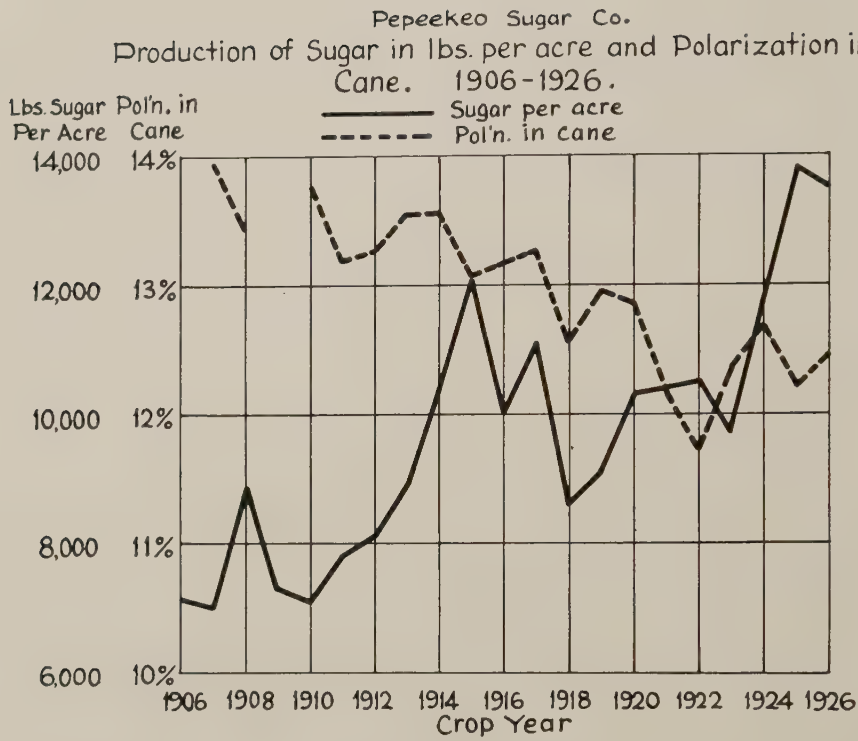

Chart M

Polarization of Cane in Different Years

In Table IV we have the polarization per cent cane for the years for which data are available. As will be seen from this table and also from Chart M, the polarization per cent cane has been decreasing progressively. In view of this, absolute comparison between two years widely separated will not be justified. We have expressed the polarization in different years as departures from a moving three-year average. Thus, to obtain the departure for 1911, we have taken the average of 1910, 1911 and 1912, and then we have calculated the departure from this average. The departures are given in Table XIII.

TABLE XIII

POLARIZATION IN CANE DEPARTURES

Year	Polarization in Cane	Three-Year Moving Average	Departures
1910	13.80	.....	.....
1911	13.21	13.41	—.20
1912	13.23	13.33	—.10
1913	13.54	13.44	+.10
1914	13.55	13.38	+.17
1915	13.05	13.26	—.21
1916	13.17	13.16	+.01
1917	13.25	13.00	+.25
1918	12.57	12.93	—.36

1919	12.97	12.80	+.17
1920	12.85	12.66	+.19
1921	12.15	12.23	—.08
1922	11.70	12.07	—.37
1923	12.37	12.26	+.11
1924	12.70	12.43	+.27
1925	12.21	12.45	—.24
1926	12.45	11.98	+.47
1927*	11.29	11.87	—.58

Formation of Sucrose

The formation and accumulation of sucrose in the cane proceeds at various stages and different rates. In the early stages of its growth, the plant goes on adding to its volume without regard to the storing of sugar. When any part is fully formed and developed then this part starts to convert the reducing sugars into sucrose and store it as such. It is believed that this rate of accumulation proceeds at varying rates. Verret and Das (5) have shown that in the case of sugar cane the rate of vegetative growth is at its maximum at five to ten months of age. There is every reason to believe that the rate of accumulation of sucrose will be at its maximum some time later. Prinsen Geerligs (6) gives the following information regarding the formation of sucrose:

	Sucrose	Glucose	Fructose
Tops of cane—6 months old	1.02	1.24	1.25
Tops of cane—9 months old	1.90	1.30	0.70
Botton joints—12 months old	16.50	0.60	0.20

It is seen from the above that accumulation of sucrose must have proceeded at a rapid rate after the ninth month, i. e., after the vegetative growth started to slow down. This is in agreement with our deductions from observing the rate of growth.

It is believed that the relationship between growth and sucrose formation is such that if growth slows down for any reason the manufacture and storage of sucrose goes on at an increased rate. Factors that help growth hinder the storage of sucrose and vice versa.

The amount of sugar stored in a cane plant will also depend on the total amount of cell space in the plant. A period of active growth, followed by a period where growth is slow, is likely to produce a high sucrose content in cane.

Temperature and Sucrose

In Table XIV and Chart N are given the co-efficient of correlation between polarization in cane, temperature and rainfall. As regards temperature there is no co-efficient of "critical" importance. But there are a few periods of interesting significance. Temperature is seen to have a negative correlation in some of the

* 1927—Calculated from two-year average.

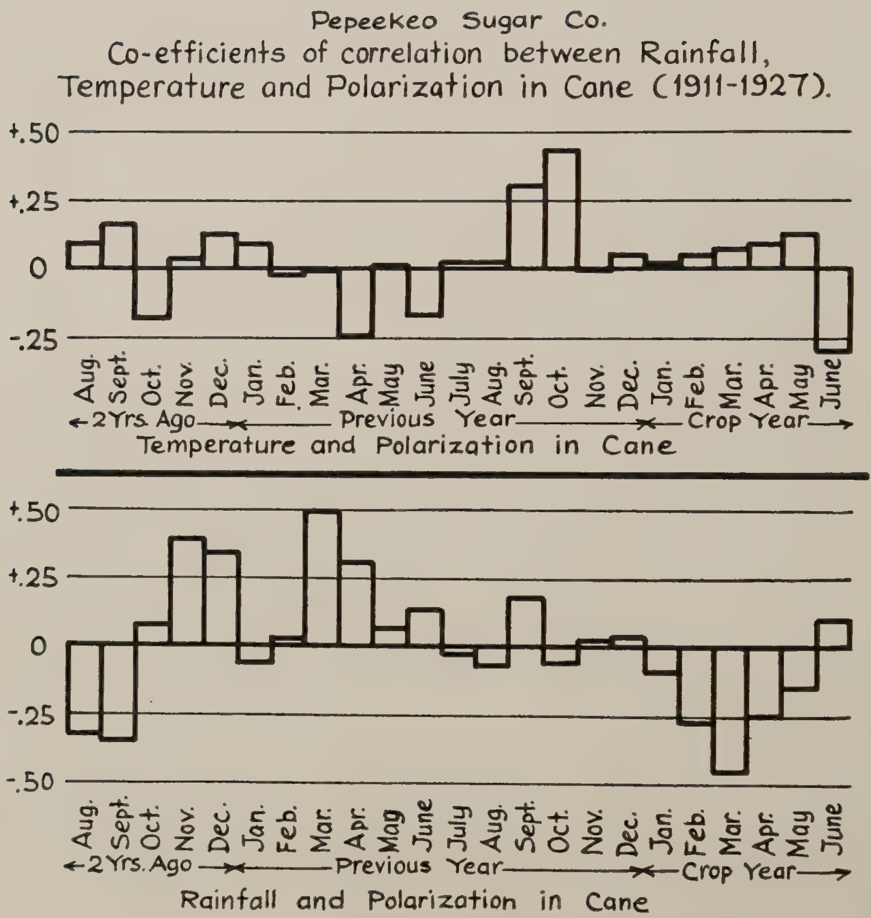

Chart N

earlier months, and a positive correlation with sucrose during the final stages of the crop; that is, high temperature during the earlier months is not helpful to sucrose formation, but during the later period it is.

High temperature during the earlier stages helps vegetative growth and probably, because of this very reason, hinders the storage of sucrose. It is possible that with certain exceptions, and limitations, high temperature during the ripening period actually increases the concentration of sucrose by evaporating the surplus water in the cane.

Rainfall and Sucrose

Though there is no period of "critical" importance, yet there are two periods which are almost so. These are the months of March of the crop year and of the previous year. There are also two other periods of very great significance in that a series of succeeding months seem to have the same helpful or harmful effect. These are the months of February to June, inclusive, of the previous year, and the months of January to May, inclusive, of the crop year. The first period of

five months, and including the near-critical month of March, is positively correlated with the storage of sugar, while the second period of five months, including the near-critical month of March, bears a negative correlation to polarization in cane.

As we have seen before, the month of March is usually the wettest month of the year. A very wet March in the year previous to the crop year, coming at a time when the cane is young, is likely to slow down growth, especially because of the prevalence of very low temperature in this month. The rainfall in this month is seen to have a negative correlation with crop yield, which, in view of the fact that it has a positive correlation with polarization, would seem to suggest that negative crop yield at this period must have been brought about by lowered yield of cane tonnage.

TABLE XIV

CO-EFFICIENTS OF CORRELATION BETWEEN TEMPERATURE, RAINFALL AND POLARIZATION IN CANE

(1911—1927)

		Rainfall and Polarization	Temperature and Polarization
Two years ago	August	—.23	.09
	September	—.25	.16
	October	.08	—.19
	November	.39	.03
	December	.34	.12
One year ago	January	—.06	.09
	February	.07	—.03
	March	.49	—.01
	April	.30	—.25
	May	.06	.01
	June	.13	—.18
	July	—.03	.01
	August	—.07	.01
	September	.17	.30
	October	—.06	—.43
	November	.02	—.01
	December	.03	.05
Crop year	January	—.09	.01
	February	—.28	.05
	March	—.46	.07
	April	—.25	.09
	May	—.15	.12
	June	.10	—.31

It is, therefore, reasonable to believe that high rainfall in March of the previous year, coupled with the usual low temperature, slows growth considerably, and probably helps storage of sugar for this very reason.

There is also another consideration that is of significance. As has been shown by Prinsen Geerligs (6), the rate of sugar manufacture proceeds at a rapid rate in that region of a cane plant which has stopped to grow actively, which will be at about 12 months of age.

In the month of March, a year previous to the crop year, most of the cane is at the age when rapid accumulation of sucrose is taking place. This rate is, no doubt, further accelerated by the slowed growth process.

The same considerations, perhaps, apply to the whole period of five months from February to June of the previous year.

The harmful effect of high rainfall in the ripening and grinding season is everywhere recognized. High rainfall at the last stages causes harm because of several reasons: (1) it dilutes the juices and lowers the percentage of polarization; (2) it may, coupled with other factors, break down a part of the sucrose into other sugars; (3) it may help start new lateral shoots which will draw on the stored sucrose in the cane.

It is seen that at Pepeekeo rainfall is of greater significance than temperature in regard to the polarization in cane. It is not, however, suggested that the same will hold true in every place. We believe that both temperature and rainfall have a great bearing on the sucrose content of the cane. In other words, we may say that sucrose per cent in cane depends, among others, on two important factors, namely, temperature and rainfall. Of these two variables, the one that varies to a greater extent than the other will exert greater influence. If in any locality the range of temperature variation is comparatively greater than rainfall variation, then we may expect that sucrose content will vary more in accordance with temperature than with rainfall. The opposite will hold true in cases where rainfall variation is greater.

"Active" Rainfall and Polarization

We have seen that as regards the effect of rainfall on sucrose content we have two periods of significance. One period consists of five months from February to June, one year previous to the crop year, and the other of five months from January to May of the crop year. Both periods are of equal duration, and it appears that both periods have just about the same importance. The first period has positive correlation, and the second one a negative correlation to sucrose content. If we ignore for the time being the effects of rainfall in the other months and also the effect of temperature, then we can say that fluctuations in the polarization per cent cane from year to year are brought about by the resultant activity of these two periods.

To express in a simple manner the resultant effects of these two periods, we have used a term "active" inches of rainfall. The "active" inches of rainfall in regard to any crop year are obtained in the following manner: We will assume that rainfall in the first period makes or helps to make sucrose in cane, and that high rainfall in the second period tends to destroy the sucrose already formed. We will take, then, that the difference in rainfall between the first and the second period, added or subtracted from the first period, will give us the amount of "active" rainfall. If the first period has more rainfall than the second period, then the result will be so many inches difference in rainfall in favor of the first period, and exerting a proportionate influence in the same direction. If the second

period has more rainfall than the first, then the result will be the difference which will counteract the good influence of the first period.

To illustrate: The first period has a rainfall of 50 inches, and the second period 60 inches. "Active" rainfall will be 50″—(60″—50″) or 40″.

Again, if the first has a rainfall of 50 inches and the second 40 inches, then the "active" rainfall will be 50″ + (50″—40″) or 60″.

In other words, if the second period has more rainfall than the first, it helps to decrease, and if it has less rainfall, it helps to increase the amount of sucrose already formed.

In Table XV we give the "polarization" in cane for different years and the "active" rainfall in the related period. The data are shown graphically in Chart O.

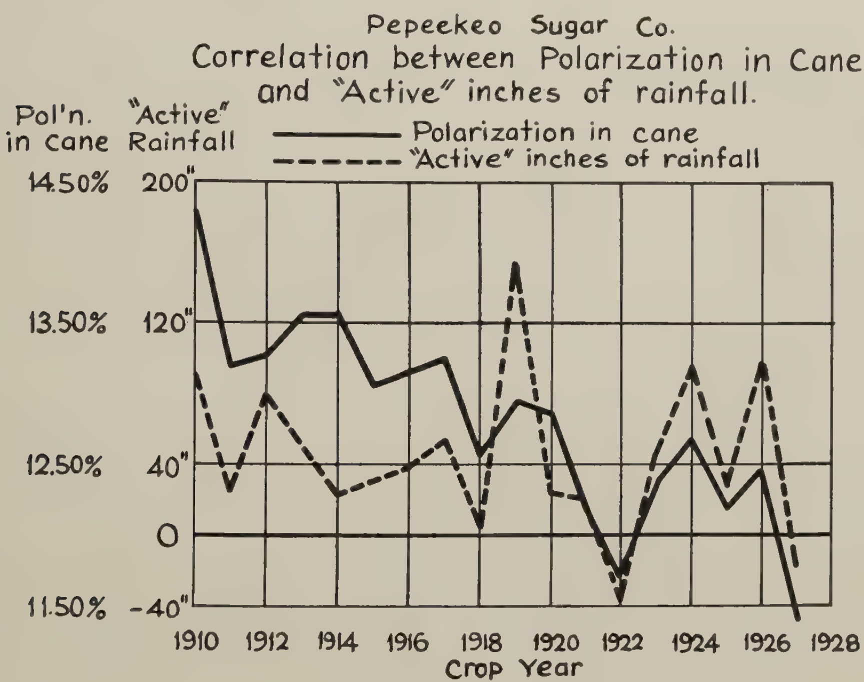

Chart O.

From Chart O we see that the fluctuations of polarization per cent cane from year to year show a remarkable relation to the fluctuations in the amounts of "active" rainfall from year to year.

It therefore follows that the sugar per cent in cane does not depend entirely on the conditions prevailing during the grinding and ripening season, but depends almost as much on the weather conditions in a previous period.

1927—Low Polarization in Cane

The year 1927 has been the poorest year from the point of polarization in cane. In the light of what has been said before we are in a position to explain the cause of such poor juices at Pepeekeo this year.

In the months of February to June of 1926 rainfall amounted to only 20.51 inches, while in the five months period of January to May, 1927, the amount was 56.88 inches—"active rainfall" was, —17 inches. This has no doubt been a great factor in determining the quality of juice.

TABLE XV

"ACTIVE" INCHES OF RAINFALL AND POLARIZATION IN CANE AT PEPEEKEO

Year	Polarization in Cane	Inches Rainfall Feb.-June Previous Year	Inches Rainfall Jan.-May Crop Year	"Active" Rainfall (in Whole Numbers)
1910	13.80	65.90	38.72	92
1911	13.21	45.72	68.08	24
1912	13.23	63.45	45.66	80
1913	13.54	53.52	61.11	47
1914	13.55	37.11	53.22	21
1915	13.05	60.66	38.35	84
1916	13.17	45.08	52.70	37
1917	13.25	50.45	46.28	54
1918	12.57	53.46	103.65	2
1919	12.97	93.29	32.20	154
1920	12.85	32.78	40.73	25
1921	12.15	38.74	58.51	19
1922	11.70	29.48	95.97	—38
1923	12.37	74.91	105.60	43
1924	12.70	70.32	45.08	95
1925	12.21	44.16	59.94	28
1926	12.45	56.34	22.06	100
1927	11.29*	20.51	56.88	—17

It is also seen from the weather records that in the grinding and ripening season of the 1927 crop, average monthly temperature was a few degrees higher than the normal; rainfall in the same period was abundant and well distributed. The combined effect of temperature and rainfall was, no doubt, calculated to produce new vegetative growth. This new growth reduced the already meagre store of sucrose. A combination of factors—not one factor—has been responsible for such poor quality of juices.

Though it does not have any direct bearing on Pepeekeo, still it may not be out of place to refer to a report of R. H. McLennan. Writing from Grove Farm, Kauai, on September 23, he says that a field of U. D. 1, harvested in the middle of September, contained from 45 per cent to 50 per cent suckers in the cane sent to the mill.

Knowing that millable cane does not start to form before the cane is about six months old, we can easily trace that most of the suckers must have started to grow in the winter months—December to March.

* Figure up to end of August only.

Well distributed rainfall and high temperature during the ripening and harvesting season has been a marked phenomenon in most of the plantations in these Islands. Pepeekeo had the same conditions as Grove Farm Company. It is not, therefore, unreasonable to assume that at Pepeekeo also a substantial percentage of the crop harvested this year included cane of tender age and very little sucrose.

Conclusions

(1) A study of weather conditions at Pepeekeo—namely, of temperature and rainfall—reveals that these have contributed to a large extent to the yield of sugar per acre from year to year.

(2) At Pepeekeo the mean temperature during the months of August, September and October, two years previous to a crop, and rainfall in the month of August, one year previous to a crop, appear to exert very great influence on the yield of sugar per acre in that crop year.

(3) Independently of other considerations, polarization in cane appears to be greatly influenced by the rainfall in two periods. The first period includes February to June of the year previous, and the second period January to May of the crop year. High rainfall in the first period tends to help or increase the formation of sucrose, and that in the second period tends to decrease the amount of sucrose already formed.

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Notes on *Pythium* Root Rot of Sugar Cane

By C. W. Carpenter

These notes discuss various phases of *Pythium* root rot for the purpose of giving those following our work an outline of some things we are trying to do, and do not represent an attempt to write a scientific treatise on the results of complete investigations.

Recently, investigators of root rot of cane in Hawaii have come to consider the disease a complex of some half dozen factors, of which parasitic fungi is but one. The subject of the writer's previous investigations was the root failure and crop failure of the type we were observing in certain areas on Oahu, specifically with Lahaina cane in the Waipio and Waipahu district. It was concluded then that a species of *Pythium* was the primary cause. Several other factors concerned in root rot while observed, were not investigated at that time, and some of these are now appropriately being studied in the departments of entomology and chemistry.

Lahaina Disease and the Root Disease Complex

In extending the researches on the general problem of root disease under the conception of the root disease complex*, the following factors have been included under cooperative investigations between the departments of chemistry, entomology and pathology: 1. Aluminum and ferrous iron toxicity of the soil. 2. Unfavorably high concentrations of mineral salts in the soil. 3. Nematodes of the genus *Heterodera* attacking the cane roots. 4. Nematodes of the genus *Tylenchus* attacking the roots. 5. The effect of unfavorable ratios of replaceable bases. 6. The effect of Isotomodes and other small soil-inhabiting fauna. 7. Fungous root rots.

The variety Lahaina continues to be largely used for root disease studies. It has been stated several times, and may well be emphasized here, that in seeking to find the causes of the root diseases of Lahaina cane, we are not trying to restore this variety to commercial prominence. We are using this susceptible variety rather as a key to the combination of root failure in general.

The failure of the Lahaina variety throughout the sugar cane countries of the world could not logically be attributed to combinations of factors unless we are ready to admit that vegetatively propagated plants deteriorate *per se*. We must logically seek one factor or a small series of related factors,—fungous root parasites, for example, as the primary cause of this extensive growth failure. First in one country and then in another, cane planters' experiences repeated themselves with this variety. Commercially it scarcely exists today. And still this variety does not appear to be vegetatively weakened. It will grow well in many soils virgin to cane.

Old ratoons continued to yield well according to the experiences of some of our planters, but when plowed out and replanted to Lahaina the results were disappointing. This seems to be the result of a balanced relation between the large root system of the ratoon and the root disease; when the cane is replanted, very few roots starting out have to contend with an accumulation of root organisms nourished by the old stool. A resistant variety, while being attacked to some extent, is able to produce root area faster than it can be destroyed by the root disease.

Can it be that the unfavorable factors of physical and chemical composition of cane soils were so generally distributed and so suddenly became primary

* Agee, H. P. In Reports of the Association of Hawaiian Sugar Technologists, 1926, pp. 5-10.

factors in the succeeding epidemics of root disease of Lahaina in the cane countries of the world? Entire plantations had to be replanted to other varieties in two or three years. It seems more probable that living parasites of the roots are the primary factors in such recurrent outbreaks. The non-living factors conceivably are often but predisposing causes; often they are independent in their action, and more or less localized in their distribution. They are not epidemic in nature, though often able to spread or seem to spread in their effects in more or less contiguous areas where soil conditions are similar, agricultural and fertilization practices uniform, water supplies of like character, etc. Neither combinations of such factors nor any one of them would we expect to similarly devastate a variety of cane on the diverse cane soils, and under the varied agricultural practices of cane culture of the world, still permitting commercial culture of closely related strains. This sort of disease resistance seems to be identical with resistance to a fungous parasite. Steam or formalin sterilization of sick soils likewise permits of normal growth of this variety in pot cultures.

We should not minimize the harmful effect of: (1), any unfavorable chemical and physical factors of the soil that we find to apply to the various commercial varieties in different degree in Hawaii, and (2), variability in degree of compactness of the soil, stagnation of soil water, etc., as the Java writers state to be the cause of root disease of cane under their conditions. It seems more logical for a universally active disease such as root rot of the Lahaina variety, to consider living parasites primarily responsible.

The other factors do cause retarded growth and growth failure in Hawaii, the extent of which is being determined by the departments concerned. That they are universally active is not claimed by those studying these aspects of the problem. The interrelations of the physical and chemical soil environment and the living parasites of the roots remain largely to be determined.

After the role of the various living factors prejudicial to normal root development of present standard canes has been more completely investigated, we will have some idea of how much damage they are causing.

This broader conception, taking in all known factors in root failure, under the general project "root disease complex," is an advance in root studies, which means progress, not only in the investigation of the specific type of disease referred to above, but in all cane root failures, since a cooperative study by workers in several departments was the natural outgrowth of this broadened viewpoint.

Pathological Considerations

Of the cane root inhabiting fungi in Hawaii, a species of *Pythium**, described by the writer as morphologically identical with *Pythium butleri* Subramaniam and *Rheosporangium aphanidermatus* Edson, now perhaps more appropriately referred to as *Pythium aphanidermatum* (Edson) Fitzpatrick†, is the only one of demonstrated parasitic habit. The vast number of species of bacteria and fungi other than *Pythium aphanidermatum,* which, at times, may also be found in and

* Bull. of the Exp. Sta., H. S. P. A., Bot. Ser., Vol. III, Part 1, p. 64, 1921.

† Fitzpatrick, H. M. *Mycologia* 15, p. 166, 1923.

about cane roots, remain to be considered. Similarly the other biological factors have scarcely been touched. It is believed that the most logical method to approach a solution of the root failure problem, as it applies to our present standard varieties, is by gaining thorough knowledge of the factors concerned. While methods of control may be enthusiastically studied where there seems to be a basis for a theory, the results of our study promise most success if the factors involved are taken up and understood a few at a time. In this department we are attempting to learn more about the nature of *Pythium aphanidermatum* and related forms, and any other fungous or bacterial inhabitants of the roots, together with the relations of any parasitic forms to: (1), the cane plant; (2), the physical and chemical composition of the soil; (3), to other root parasites; (4), to the biological population of the soil; and (5), to chemical antiseptics and disinfectants. As to the possibilities of the last-mentioned as a means of control, we maintain a conservative outlook, since this means the discovery of a substance which will destroy or restrict one form of life in the living soil, and yet be practically harmless to the cane roots as well as the beneficial organisms of the soil.

As opportunity permits we plan to make some physiological and histological studies pertinent in their bearing on the life history of the organisms and disease resistance. We expect the growth failure investigation to benefit largely by the close cooperation between the several departments concerned.

Occurrence of *Pythium aphanidermatum* in Hawaii

In the course of our investigations in various localities of the four Islands where cane is grown, we have a record of this fungus on the cane varieties mentioned below.

Lahaina, E. K. 28, H 146, D 1135, Yellow Caledonia, H 109, Porto Rico Uba, Kassoer, Natal Uba, 20-S-20, P. O. J. 213, and P. O. J. 36.

A related form of *Pythium* or possibly *Aphanomyces,* with a rough walled oospore, first observed on H 109 at Wailuku in 1920, has been seen in association with diseased roots of Lahaina cane at Olaa, Onomea, Pepeekeo, and Honokaa, on Hawaii, and on H 109 at Olowalu, Maui.

E. K. 28: We are of the opinion that the variety E. K. 28, recently introduced into our Makiki and Alexander Street experimental plots, will prove unsatisfactory where *Pythium* root rot is a factor. At the Makiki plots this variety is very promising and shows no indications of weakness arising from the existing soil conditions; but at Alexander Street, where we have some history of root rot in other varieties, E. K. 28 is an unqualified failure.

Examinations of the roots of moderately diseased plants, as well as those almost dead, revealed the *Pythium* fungus in abundance, and it was the only parasitic type of fungus isolated. Nematodes are not an important factor here and the condition of the soil appears most favorable. Pure cultures from these isolations are now considered to be *Pythium aphanidermatum.*

The variety E. K. 28 has a root rot history in Java. Regarding this variety Lyon* writes as follows:

In recent years a seedling cane known as E. K. 28 has become the leading cane variety in Java, and now occupies fully 40 per cent of the total cane growing area of the island. This seedling is very subject to root rot, however, and in 1921 the disease became so prevalent in E. K. 28 that some expressed fears that the variety would be eliminated altogether. This scare caused many growers to turn from E. K. 28 to other more resistant varieties in their plantings for the 1922 crop.

Dr. Kuyper's description of root rot in Java tallies very closely with the symptoms of the disease as displayed by Lahaina cane in Hawaii. He asserts that the malady occurs in practically all the cane varieties of Java.

It may be said that Dr. Kuyper, according to Lyon's resumé of his work, while offering no proof of his theories, is nevertheless confident in his statements. According to him the disease is caused by a lack of oxygen, a temporary or constant anaeroby, as for instance, in a soil supersaturated with standing water and, therefore, low in oxygen, etc. His contentions should not be difficult to prove if they are correct.

We know that cane is rather tolerant to fluctuations in the ration of water. A soil organism like *Pythium,* which requires water for growth and for the dissemination of its zoospores, would be a stronger factor in root rot when there is sufficient water for these purposes. With sufficient water it can spread rapidly and seriously rot the roots in a few days, and when the plant symptoms show above ground, as I have previously pointed out†, it is too late to find the organism in abundance. The conception I favor now is that *Pythium* root rot is comparable in its rapid attack, and the transitory period thereof, with the *Phytophthora* blight of potato tops. When the conditions are right the damage is done in a very short period, and several days or weeks later is not an opportune time to look for the parasite. With *Pythium* root rot the half-dead plants are not as suitable material for observing and isolating the causal organism as the seemingly healthy plants close by the diseased area. Here it is often working in a moderate way, alive and active, awaiting more favorable conditions for the next outbreak.

It seems more reasonable to suppose that the cause of a serious root rot like this is favored by water rather than to assume from circumstantial evidence that either excess or deficient water in combination with various soil conditions has swept Java with a root rot scourge, and by inference, the cane countries of the world under all types of soil, selecting primarily the Lahaina type.

The writer agrees with Lyon that while Dr. Kuyper's explanation may seem sufficient to those familiar with the disease in Java only, it certainly will not convince those studying root rot elsewhere.

In this connection some recent observations at the new substation at Kailua, Oahu, are rather significant.

At Kailua, where Lahaina cane together with H 109 was planted in January, 1927, in former rice patches, the former variety is growing at a rate comparable with the latter and shows no signs of distress. A stool was recently removed and

* *Hawaiian Planters' Record,* Vol. XXVII, p. 259. 1923.

† Bull. of the Exp. Sta., H. S. P. A. Bot. Ser. Vol. III, Part 1, p. 62, 1921. See also *Hawaiian Planters' Record,* Vol. XXIII, No. 3, pp. 155-159, 1920.

the root system examined. It was one of the best root systems we have ever seen. Not a single spot or flaw suggestive of root injury could be found.

Young Lahaina cane located near by in the same type of soil is beginning to show distress of scattered stools. Such plants removed and examined revealed on the roots of a stunted stool, lesions typical of *Pythium* root rot, and on the roots of a healthy plant about ten feet away, no sign of *Pythium* could be found. The fungus was isolated in pure culture from the roots of the stunted cane.

This field is a recently acquired rice patch of the heaviest soil, shallow, poorly drained, soggy, and with a puddled subsoil of a rubber-like consistency. If the theories advanced in Java as to the nature of the soil itself being the cause of root rot were correct, we should not expect to be able to grow a stick of cane under these extreme conditions. Of course this area is being drained and improved, but the larger Lahaina mentioned was planted in midwinter, and the succeeding six months before adequate drainage could be provided, was a period of unusually heavy rainfall reaching freshet proportions at times. The evidence here supports the view that *Pythium* is just getting established, and we await further developments with interest.

H 109: On the standard variety H 109, *Pythium aphanidermatum* is occasionally found. Where small areas of this variety suffer from growth failure, and *Pythium* is present, it does not appear to be present in sufficient amount to be the primary factor involved. Where *Pythium* has occurred on H 109 in an alarming amount it has subsequently been demonstrated in some instances that there was a definite deficiency in soil nutrients or an unfavorable soil composition. Apparently *Pythium* does not occur with greater frequency nor does it do more damage on H 109 than it did seven years ago. At that time it was stated that the resistance of H 109, D 1135 and Yellow Caledonia was relative and not absolute.

Relation of *Pythium aphanidermatum* to Nematodes

In cooperative studies with R. H. Van Zwaluwenburg we have not observed any support for the view that the punctures of nematodes furnish the entrance channel for *Pythium aphanidermatum*. This view may be true for some of the less aggressive fungi and wound parasites, but in general there seems to be no intimate association of nematodes and *Pythium*. This latter is capable of entering the roots freely, both cortex and stele, in sterilized soil inoculated with the fungus in pure culture. Nematodes and *Pythium* do occur often on the same root systems, but we have observed no interdependence in their relations. *Pythium aphanidermatum* on the contrary seems to prefer a healthy root for its nourishment.

Relation to Soil Reaction

Preliminary experiments have determined the fact that one strain of *Pythium aphanidermatum* when cultured on a buffered nutrient medium can grow over a range of hydrogen ion concentrations comparable with those exhibited by most of our sugar cane soils. This suggests that adjustment of soil reaction is not feasible as a means of control.

Relation of Temperature and Moisture

We have almost no experimental data in regard to the relation of *Pythium aphanidermatum* to temperature and moisture factors. In this equable climate we would expect very slight variations of soil temperatures between day and night, the only changes to be expected would be the slightly lower soil temperatures of seasonal variation in the winter months. Any effect of temperature in relation to root disease seemingly is a result of rate of growth on the part of the plant rather than a direct reaction on the fungus. Slower root development allows the parasite to destroy root area faster than it is replaced.

Essentially the *Pythiaceae* are water fungi, though some forms have taken to a terrestrial life. This group is dependent on moisture for completing the asexual or zoospore stage, but *Pythium aphanidermatum* grows less actively in the vegetative stage in deep liquid cultures than on agar surfaces, indicating a preference for a solid substratum for vegetative growth or a semi-aquatic type of life-cycle.

Sufficient moisture for good growing conditions of the cane plant offers sufficient moisture for the purely vegetative processes of the fungus in getting from one root to another. With occasionally increased supplies of soil water the zoospore stage offers a means of wider dissemination.

Notes on Root Rot on the Island of Hawaii

A trip was made to Hawaii, August 16-22, to inspect the Lahaina plantings made in cooperation with the Olaa Sugar Company, Ltd., Honokaa Sugar Company, Onomea Sugar Company, and Pepeekeo Sugar Company. The object of this cooperative planting of Lahaina cane where it failed many years ago (1896 and on), was to find how this variety would grow now, and if it suffered from growth failure, to find if possible the nature of the causal factors.

The cause of the growth failure of Lahaina in the Hamakua and Hilo districts in the closing years of the last century has long been a subject of interest. The first inspection of the Lahaina plantings, reported in detail herein, revealed in every plot a more or less active "root rot" of the sort we have associated with invasion of the roots by fungi of the genus *Pythium*. The presence of *Pythium* species in the roots of the Lahaina in all four localities and at several elevations from 100 to 1250 feet considered in relation to our previous experiments with this type of fungus supports the view that *Pythium* species were a very important factor in the serious growth failure of Lahaina in former years.

Further inspection at intervals of a few months are expected to prove helpful in advancing our knowledge of growth failure. Through the cooperation of the chemistry and entomology departments, representatives of which join in the inspections, progress is anticipated in determining the relation of *Pythium* and nematode species as causal factors in root failure and in revealing something as to the nature of the environmental soil factors involved.

Observations made on this trip are first reported by the plantation, followed by a summary of preliminary data. Seed was furnished in each case by the Experiment Station, H. S. P. A. Data as to area, elevation, planting dates and fertilization of the respective plots are incomplete, but this will be furnished us later and incorporated in subsequent reports.

OLAA SUGAR COMPANY, LIMITED

Field "W", Sec. "B" of Sec. 1
Area, about 1/20 acre
Planted, May 20, 1927
Elevation, about 1000 feet

The Lahaina was about two and one-half to three feet high and had made a fair germination; growth compared favorably with the adjoining D 1135 which is about one week older. The cane was not as vigorous or healthy in appearance as the Lahaina in Field J-2 of this plantation, largely due perhaps to climatic and soil differences. Three plants were removed, the root systems exposed by washing and specimen roots preserved for later observation.

All plants examined had poor root systems with a considerable number of roots showing red cankered spots, red cankered girdling areas and flaccid root tips. Even the young primary roots issuing from the base of the young shoots were similarly affected. Forced branching was common, following rot of the tip of the primaries.

Microscopical observations: Typical spores of *Pythium aphanidermatum* were found in quantity in some of the diseased roots. Typical *Pythium* type mycelium was seen in interior cells and surface cells in close association with the red cankered areas. Several roots had the tip cut off by deep, girdling, red cankers, with the soft tips containing *Pythium* spores and mycelial hyphae.

A few brownish spores with rough walls, in contrast to the smooth wall of *Pythium aphanidermatum,* were noted in this material. My earlier notes record similar oospores in association with root rot of H 109, February 12, 1920, in Field 49, of the Wailuku Sugar Company, where *Pythium aphanidermatum* was active. This is an associated form necessitating further investigation, and is possibly another *Pythium* or a member of a closely related group such as *Aphanomyces.*

D 1135: A young stool of D 1135 in an adjoining field was examined for root conditions. On the roots a few red cankered lesions were detected. However, upon later examination, no significant facts were observed.

Field J-2
Area, 1/20 acre
Planted, May 20, 1927
Elevation, about 300 feet

The Lahaina cane showed a better growth here than in Field W, Sec. B of Sec. 1 of Mountain View, and though it had germinated well, the plants in general were rather small compared with the near by Yellow Caledonia. The plants were about two and one-half to three feet high, and smaller than the Yellow Caledonia by about one-third.

Several plants were removed and the root systems washed out. Poor root systems were the rule. Few live roots were seen except the very youngest. There was a noticeable lack of fibrous roots; flaccid root tips and forced branching of the primaries were common even in the comparatively vigorous appearing plants; the young roots, too, were often flaccid.

Microscopical observations of the softened roots showed numerous spores of *Pythium aphanidermatum*. In addition, associated with some roots, mostly externally, were the rough-walled *Pythium* type spores mentioned above in Field W, Sec. B. They were yellowish-brown in color and, roughly, twice the diameter of the spores of *P. aphanidermatum,* though the interior spore itself exclusive of the rough appendage was approximately the same size.

Some large roots showed only hyphae of *Pythium aphanidermatum* type in the cells, though determinations in such preserved material are often unsatisfactory.

HONOKAA SUGAR COMPANY
Field 29
Area, about one-half acre
Planted, April 18, 1927
Elevation, about 500 feet

This Lahaina was planted in a field where H 109 did rather poorly. Adjoining the Lahaina plot now are D 1135, P. O. J. 36 and 213.

The Lahaina had germinated poorly, but growth compared well with adjoining cane. Some seed pieces were just sprouting, and on some the band roots had not started, or, if so, only on one side of the set. Several plants were removed and examined. The roots of the larger plants were in good condition, not having many lesions, while those of the smaller plants had poor root systems. Observations later revealed numerous typical oospores of *Pythium aphanidermatum,* and it was concluded that *Pythium* root rot was present though not in as active a state as sometimes seen.

H 109: Some of this variety which was growing across the road and pipe line from the Lahaina plot was doing poorly and was being replanted. Examination in the gross and microscopically revealed no *Pythium.*

Field No. 6
Area, about one-half acre
Elevation, about 1250 feet

The first lot of Lahaina seed germinated poorly and after two or three weeks replants were made with a second lot. The stand was uneven with two series of plantings, but discounting for this, the Lahaina was not as vigorous as that in the lower field (Field 29). Roots examined from plants of both sizes showed a restricted development with soft, flaccid tips, characteristic of the *Pythium* type of rot. Microscopical observation later showed the *Pythium* type mycelium packed in the cells, but pre-sporangia or other definite criteria of *Pythium aphanidermatum* were not found. Of interest was the occurrence in abundance here also of the rough-walled *Pythium* oospores mentioned above, in the soft and decayed roots.

ONOMEA SUGAR COMPANY
Field 33
Elevation, about 1200 feet

Although Mr. Moir took especial care of his allotment of Lahaina seed, this upper field was in decided contrast to the good, even stand in the plot in Field

34. This upper field showed a poor stand, with scattered, rather pale-looking plants, compared with Yellow Caledonia and D 1135 adjoining. This is a cool, wet location on the flat top of a mountain ridge.

Several small and large plants were dug, washed and examined. The seed or band roots were rotted off already, and scarcely a healthy appearing root was found. New primary roots originating on the base of the shoots were badly red cankered, watery translucent to yellowish in appearance. There were no fibrous roots. This Lahaina was in a precarious condition already, and if existing conditions persist, little growth can be expected.

Microscopical observations: Oospores of *Pythium aphanidermatum* were present in the reddened and yellowish water-soaked root areas of large, short, young roots arising from the base of the stalk. This appeared typical *Pythium* root rot at date of observation.

Field 34
Elevation, about 400 feet
Mud press, 15 tons per acre, was spread before planting

Here the Lahaina was growing in a good, even stand, as a result of good germination. Unusual precautions were taken by Mr. Moir to insure a good start for both these experimental plantings at Onomea. The plants were about four feet in height.

Average plants, as well as large and small plants from various parts of the plot, all had developed a fairly good root system, but this was now breaking down badly. The older roots were rotted and blackened, while the new primaries from the stalk base were badly cankered with red spots of infection, and had a general water-soaked, translucent, yellowish to red appearance, with flaccid tips rather common.

Only one of the plants examined had any noticeable recent development of fibrous roots on the older primaries, the latter being now badly rotted and almost severed from the plant. The newest shoot roots, about three to four inches long, were rotted the whole length before any secondaries had a chance to develop.

Apparently this Lahaina made a good start and grew well until recently, when the conditions favored root rot. The whole root system, old as well as new roots, was breaking down. It may be noted that this soil is in an excellent state of tilth, being deep and easy to work.

Microscopical observations: Oospores of *Pythium aphanidermatum* as well as pre-sporangia of this fungus were found, but not in the abundance I anticipated from the typical appearance of the rot and the degree of development. However, once more the presence of an associated *Pythium*-like fungus with rough-walled oospores was observed, as noted previously at Olaa, Honokaa, and later at Pepeekeo. From some unpreserved material from this field at Onomea an attempt is being made to isolate one or both *Pythium* types.

Yellow Caledonia: Adjoining the Lahaina is Yellow Caledonia. A small plant was dug up and examined. Root lesions, though not common, were found. Examination later showed the new rough-walled *Pythium* present in great amount, in association with the rotting tips.

PEPEEKEO SUGAR COMPANY
Field 1
Elevation, about 100 feet

A rather uneven stand of Lahaina characterized this plot. The root system was fair, the new roots appeared healthy, and without the reddish lesions readily found in most of the other plots visited. Closer examination, however, revealed that the older roots as well as some younger primaries were discolored and flaccid. Many soft, flaccid roots from the base of the shoots indicated a period of rotting preceding our visit, but changed conditions appeared to have recently brought about a normal development. At this time *Pythium* root rot was not in an active phase.

Microscopical observation: *Pythium aphanidermatum* oospores were observed, but only in small numbers. Large numbers of the above-mentioned rough-walled oospores were found associated with the root rot.

Summary of First Inspection of Lahaina Plots on Hawaii

A number of plantings of Lahaina were made in the island of Hawaii in cooperation with Olaa Sugar Company, Ltd., Honokaa Sugar Company, Onomea Sugar Company, and Pepeekeo Sugar Company, for the purpose of root studies. The first examination of these plantings has proved a very enlightening experience.

While the *Pythium* type of root rot was present in varying degrees in all plots, in some fields it was in an aggressively active phase, viz.: Onomea at 400 feet and 1200 feet elevations, and Olaa at 1000 feet elevation, and possibly Honokaa upper field. It was less active at Olaa lower field, Honokaa lower field, and relatively quiescent at Pepeekeo, elevation 100 feet, at dates of observation.

The finding of the *Pythium* type of root rot in the Lahaina cane in all four localities of Hawaii, over a wide range of conditions, supports the view that this type of disease was an important factor in the earlier growth failure of Lahaina in the Hilo and Hamakua districts.

Of scientific interest was the finding of another closely related type of fungus, i. e., apparently a rough-walled oospore type of *Pythium* or *Aphanomyces* associated with root rot on all four of the plantations on Hawaii. Similar oospores were found for the first time at Wailuku in 1920 in relation with root rot in H 109.

Its significane: i. e., whether a harmless saprophyte following *Pythium aphanidermatum* chiefly in the soil conditions of Hawaii, or a parasite of importance, remains to be determined. Attempts will be made to isolate it in pure cultures for studies of parasitism. Two different *Pythium* types have already been isolated from Lahaina in Onomea Field 34, one being *P. aphanidermatum* and the other possibly the rough-walled *Pythium* oospore type.

In closing this first progress report in connection with the experimental plantings of Lahaina on Hawaii, it is a pleasure to acknowledge the kind and helpful cooperation I found everywhere at hand to facilitate the studies on root diseases.

A Study of the Relative Water Requirements of Long and Short Crops Under Intermittent and Non-Intermittent Harvesting

By H. W. Baldwin

As a basis for the following study of the Relative Water Requirements of Long and Short Crops, as influenced by the age of cane under various cropping schedules, we have assumed that plant cane will receive four irrigations the first month, three the second and two each month thereafter; and that ratoons will receive one irrigation every twenty-one days, or 1.4 irrigations per month.

We further assume that three months will be allowed for ripening the cane prior to harvest, on both long and short crops, no water being applied after the 15th and 21st months, respectively.

To facilitate calculations, Table I was prepared, using as a basis the data contained on page 38 of Renton and Alexander's report, submitted at the Forty-sixth Annual Meeting of the Hawaiian Sugar Planters' Association, 1926. Columns 1 and 2, taken from that report, represent a very fair average of the amount of water applied per irrigation, at various ages. Column 3 of the following table shows the amount applied to ratoons in 1.4 rounds per month, and column 4 shows the amount applied to plant cane in two rounds per month, etc.:

TABLE I

WATER REQUIREMENTS AT VARIOUS AGES

	Acre Inches					Total Water per Unit per Month			
						Pl. 200A Rat. 400A		Pl. 174A Rat. 348A	
Age	No. Irrigations per Month						Mil.		Mil.
Mo.	1	1.4	2	3	4	Inches	Gal. P. D.	Inches	Gal. P. D.
1	3.50	4.90	7.00	10.50	14.	4760	4.30	4141	3.76
2	3.75	5.25	7.50	11.25	..	4350	3.96	3785	3.44
3	4.00	5.60	8.00	12.00	..	3840	3.49	3340	3.04
4	4.50	6.30	9.00	....	..	4320	3.94	3760	3.40
5	4.75	6.65	9.50	....	..	4560	4.15	3930	3.58
6	5.00	7.00	10.00	....	..	4800	4.36	4175	3.80
7	5.12	7.15	10.24	....	..	4908	4.48	4261	3.88
8	5.25	7.35	10.50	....	..	5040	4.57	4386	3.98
9	5.35	7.50	10.70	....	..	5140	4.70	4575	4.15
10	5.50	7.70	11.00	....	..	5280	4.80	4605	4.19
11	5.75	8.05	11.50	....	..	5520	5.02	4800	4.37
12	6.00	8.40	12.00	....	..	5760	5.24	4915	4.46
13	6.50	9.10	13.00	....	..	6240	5.66	5425	4.94
14	6.75	9.45	13.50	....	..	6480	5.90	5740	5.21
15	7.00	9.80	14.00	....	..	6720	6.12	5860	5.34
16	7.25	10.15	14.50	....	..	6960	6.32	6050	5.52
17	7.50	10.50	15.00	....	..	7200	6.53	6260	5.70
18	8.00	11.20	16.00	....	..	7680	6.90	6695	6.10
19	8.25	11.50	16.50	....	..	7900	7.20	6878	6.26
20	8.50	11.90	17.00	....	..	8160	7.42	7119	6.48
21	8.75	12.25	17.50	....	..	8400	7.65	7310	6.66

For our first study we have assumed a 4800-acre short crop, the harvesting and planting to be carried on simultaneously, starting in January and running eight months, at the rate of 600 acres per month, of which 200 acres are plant and 400 acres are ratoons.

The 200 acres of plant cane would receive four irrigations the first month, or 14 inches per acre (column 6), or a total of 2800 inches. The 400 acres of ratoons would receive 4.9 inches (column 3) per acre, or a total of 1960 inches, a grand total of 4760 acre inches, which is found in column 7.

Column 8 represents the amounts in column 7, converted to million gallons per day. Using this column, we can now readily tabulate the total water requirements for each month.

The 600-acre unit starting in January requires 4.30 million gallons per day for the first month; 3.96 the second; 3.94 in March, etc. Similar units are started in February, March, April, May, June, July and August, and then there is an interval of four months until the next crop is started in January.

Schedule A represents the complete water requirements for one year:

SCHEDULE A

Short Crop Intermittent Million Gallons Per Day

Mo.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	4.30	4.30	4.30	4.30	4.30	4.30	4.30	4.30				
2		3.96	3.96	3.96	3.96	3.96	3.96	3.96	3.96			
3			3.49	3.49	3.49	3.49	3.49	3.49	3.49	3.49		
4				3.94	3.94	3.94	3.94	3.94	3.94	3.94	3.94	
5					4.15	4.15	4.15	4.15	4.15	4.15	4.15	4.15
6	4.36					4.36	4.36	4.36	4.36	4.36	4.36	4.36
7	4.48	4.48					4.48	4.48	4.48	4.48	4.48	4.48
8	4.57	4.57	4.57					4.57	4.57	4.57	4.57	4.57
9	4.70	4.70	4.70	4.70					4.70	4.70	4.70	4.70
10	4.80	4.80	4.80	4.80	4.80					4.80	4.80	4.80
11	5.02	5.02	5.02	5.02	5.02	5.02					5.02	5.02
12	5.24	5.24	5.24	5.24	5.24	5.24	5.24					5.24
13	5.66	5.66	5.66	5.66	5.66	5.66	5.66	5.66				
14		5.90	5.90	5.90	5.90	5.90	5.90	5.90	5.90			
15			6.12	6.12	6.12	6.12	6.12	6.12	6.12	6.12		
	39.1	48.6	53.7	53.1	52.6	52.1	51.6	50.9	44.8	40.6	36.0	37.3

Thus, taking the month of March for example, we have first a unit just starting, requiring 4.30 million gallons per day; another unit started the previous month, requiring 3.96 million gallons; then a unit which was started in January and now three months old, requiring 3.49 million gallons. The next unit, now eight months old, was started the previous August and requires 4.57 million gallons, etc. The total of this column, 53.7 million gallons, is the average amount of water required per day during the month of March. In like manner the other totals represent the requirements for the respective months.

We will now compare this short crop with a long crop under similar treatment. Obviously, the tonnage will be greater on a 24 months' crop and to get the same total yield, less acreage will be required. How much less would be required, is a matter for conjecture, as we have no definite data to go on. H. P.

Agee, in the *Proceedings of the Forty-sixth Annual Meeting of the H. S. P. A., 1926,* pages 35-37, assumes, for the purpose of argument, that a short crop of 18 months will yield 87 per cent of a 24 months' crop, and for lack of anything more definite we will assume this to be correct.

Eighty-seven per cent of 4800 acres is 4176 acres, which is the figure used in the long crop schedules. On an 8-month planting and harvesting schedule, each unit will consist of 522 acres, of which 174 acres will be plant and 348 acres ratoons. Schedule B has been worked out on this basis, and represents present common practice:

SCHEDULE B

Long Crop Non-Intermittent Million Gallons Per Day

Mo.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	3.76	3.76	3.76	3.76	3.76	3.76	3.76	3.76				
2		3.44	3.44	3.44	3.44	3.44	3.44	3.44	3.44			
3			3.04	3.04	3.04	3.04	3.04	3.04	3.04	3.04		
4				3.40	3.40	3.40	3.40	3.40	3.40	3.40	3.40	
5					3.58	3.58	3.58	3.58	3.58	3.58	3.58	3.58
6	3.80					3.80	3.80	3.80	3.80	3.80	3.80	3.80
7	3.88	3.88					3.88	3.88	3.88	3.88	3.88	3.88
8	3.98	3.98	3.98					3.98	3.98	3.98	3.98	3.98
9	4.15	4.15	4.15	4.15					4.15	4.15	4.15	4.15
10	4.19	4.19	4.19	4.19	4.19					4.19	4.19	4.19
11	4.37	4.37	4.37	4.37	4.37	4.37					4.37	4.37
12	4.46	4.46	4.46	4.46	4.46	4.46	4.46					4.46
13	4.94	4.94	4.94	4.94	4.94	4.94	4.94	4.94				
14		5.21	5.21	5.21	5.21	5.21	5.21	5.21	5.21			
15			5.34	5.34	5.34	5.34	5.34	5.34	5.34	5.34		
16				5.52	5.52	5.52	5.52	5.52	5.52	5.52	5.52	
17					5.70	5.70	5.70	5.70	5.70	5.70	5.70	5.70
18	6.10					6.10	6.10	6.10	6.10	6.10	6.10	6.10
19	6.26	6.26					6.26	6.26	6.26	6.26	6.26	6.26
20	6.48	6.48	6.48					6.48	6.48	6.48	6.48	6.48
21	6.66	6.66	6.66	6.66					6.66	6.66	6.66	6.66
	63.0	61.8	60.0	58.5	56.9	62.6	68.4	74.4	76.5	72.1	68.1	63.6

The effect of intermittent harvesting is brought out very strikingly in Schedule C, which is the same as Schedule A, with the exception that operations are stopped during May and June and resumed in July:

SCHEDULE C

Short Crop Intermittent Million Gallons Per Day

Mo.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	4.30	4.30	4.30	4.30			4.30	4.30	4.30	4.30		
2		3.96	3.96	3.96	3.96			3.96	3.96	3.96	3.96	
3			3.49	3.49	3.49	3.49			3.49	3.49	3.49	3.49
4	3.94			3.94	3.94	3.94	3.94			3.94	3.94	3.94
5	4.15	4.15			4.15	4.15	4.15	4.15			4.15	4.15
6	4.36	4.36	4.36			4.36	4.36	4.36	4.36			4.36
7	4.48	4.48	4.48	4.48			4.48	4.48	4.48	4.48		
8		4.57	4.57	4.57	4.57			4.57	4.57	4.57	4.57	
9			4.70	4.70	4.70	4.70			4.70	4.70	4.70	4.70
10	4.80			4.80	4.80	4.80	4.80			4.80	4.80	4.80
11	5.02	5.02			5.02	5.02	5.02	5.02			5.02	5.02
12	5.24	5.24	5.24			5.24	5.24	5.24	5.24			5.24
13	5.66	5.66	5.66	5.66			5.66	5.66	5.66	5.66		
14		5.90	5.90	5.90	5.90			5.90	5.90	5.90	5.90	
15			6.12	6.12	6.12	6.12			6.12	6.12	6.12	6.12
	41.9	47.6	52.7	51.6	46.6	41.8	41.9	47.6	52.7	51.6	46.6	41.8

In like manner other schedules have been worked out, but only the totals for comparison need be given here as in Table II.

It will be noted that in each case intermittent harvesting results in a lessening of the water demands, during the dry summer months. On the other hand, speeding up the harvesting and planting from 8 months to 7 months increases the water demand during the months of May to October, inclusive.

The saving in water, effected by Schedule C (short crop, 8 months intermittent), over all other schedules is remarkable. The saving over present common practice (Schedule B) is still more noticeable, and is represented graphically in the illustration. During the four dry months, June, July, August and September, there is an indicated saving of from 20 to 25 million gallons per day, and this in spite of the greater acreage involved in the short crop schedule.

The writer does not wish to go on record at this time as advocating short cropping, as there are many other considerations than water to be studied. We are merely presenting one phase of the subject in the hope that it may be of some assistance in the study of the short cropping problem:

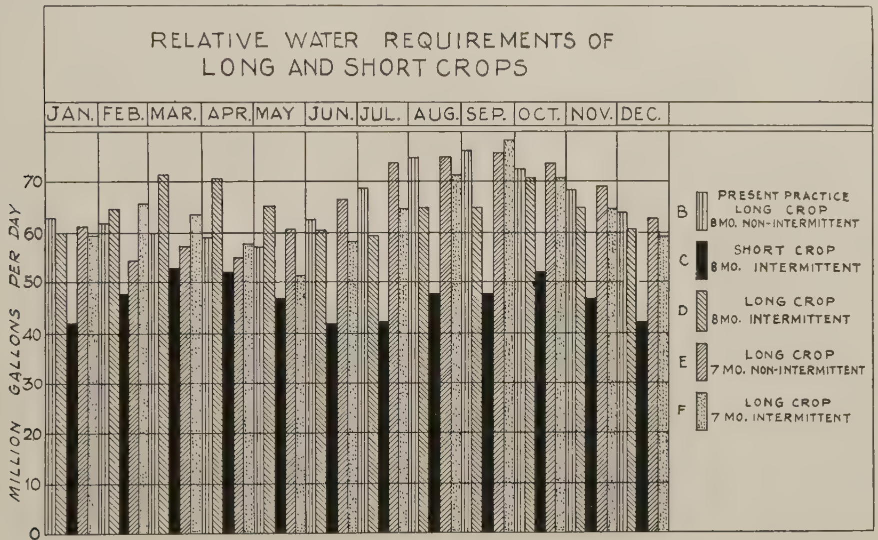

TABLE II

Water Requirements

Comparison of Long and Short Crops Under Intermittent and Non-Intermittent Harvesting

Million Gallons Per Day

Schedule	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
A	39.1	48.6	53.7	53.1	52.6	52.1	51.6	50.9	44.8	40.6	36.0	37.3
B	63.0	61.8	60.0	58.5	56.9	62.6	68.4	74.4	76.5	72.1	68.1	63.6
C	41.9	47.6	52.7	51.6	46.6	41.8	41.9	47.6	52.7	51.6	46.6	41.8
D	59.9	64.6	71.7	70.2	65.0	60.3	59.9	64.6	71.7	70.2	65.0	60.3
E	61.0	59.2	56.8	54.7	60.6	66.8	73.2	75.3	77.8	73.4	68.2	62.7
F	59.5	65.7	63.5	57.1	51.0	57.7	64.1	71.0	78.0	70.2	64.5	59.4
G	58.6	65.0	70.7	68.8	62.6	57.0	64.1	70.7	76.7	70.5	64.7	59.6
H	42.7	48.8	54.2	48.0	42.2	42.3	48.6	54.3	53.2	46.9	41.2	36.0
I	41.9	48.1	53.9	47.3	41.5	36.3	42.9	49.2	54.7	53.6	47.4	41.8

A. Short Crop: 8 months, non-intermittent; January-August, inclusive; 200 acres plant, 400 acres ratoon each month; total 4800 acres.

B. Long Crop: 8 months, non-intermittent (present practice); January-August, inclusive; 174 acres plant, 348 acres ratoons each month; total 4176 acres.

C. Short Crop: 8 months, intermittent; January-April, July-October; 200 acres plant, 400 acres ratoons each month; total 4800 acres.

D. Long Crop: Same as B, only intermittent; January-April, July-October.

E. Long Crop: 7 months, non-intermittent; January-July, inclusive; 200 acres plant, 400 acres ratoons; total 4200 acres. (Round numbers were used in this case instead of 198 and 396, as Column 8, Table II, calculated for 200 and 400 acres is near enough for our purpose in this case.)

F. Long Crop: Same as E, only intermittent; January-March, June-September.

G. Long Crop: Same as F, only January-April, July-September.

H. Short Crop: 7 months, intermittent; January-March, June-September; 226 acres plant, 452 ratoons each month.

I. Short Crop: Same as H, only January-March, July-October (3 months interval).

"Duty of Water"—A Relic of Early Irrigation Terminology

By W. P. Alexander*

This paper has been written to correct an erroneous impression which is generally prevalent in Hawaii as to the meaning of the term, "duty of water," and to urge that, due to its ambiguity, we give a clearer interpretation to our data by the adoption of standard terms which will better express what we want to say and prevent confusion.

The False Conception of the Term in Hawaii

If I am not mistaken, there are those who are in the habit of thinking of "duty of water" in relation to the amount of the crop produced. For example: Should one million gallons of water per acre give *three tons of sugar*, the duty of water is said to be high. This conception is not according to the best irrigation parlance. Duty of water *per se* has no reference to the weight of the crop grown. There is a specific duty of water for every set of conditions, and we cannot refer to ratio of water to tons of cane or sugar produced as "duty of water." It was coined to express the relation between a given quantity of water and *the area* which it serves.

History of the Term

Fortier (5), gives a good account of how Americans came to use the term, "duty of water," which is given substantially as follows:

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In the language of Brown (17), "duty of water" is a technical term used by irrigation engineers to signify the amount of work that water may be expected or ought to do in irrigating crops, and is defined by him as "the measure of the efficient irrigation work that water can perform, expressed in terms establishing the relation between the *area* of crop brought to maturity and the quantity of water used in its irrigation." The expression "efficient irrigation work" implies that the water supplied to the crop is neither more nor less than what is best for it.

During the past fifty years or more the duty of water in India has been expressed as a rule in terms of that area of crop, expressed in acres, which a discharge of one cubic foot per second, abbreviated to "cusec," flowing continuously during the life of the crop, is able to bring to maturity.

When irrigation in the western part of the United States began to be studied in a technical and scientific way by the agents of the Federal and State Governments, they adopted the custom of British engineers in India in expressing the relation between water and crop, but frequently gave in addition the same information expressed in miner's inches or fraction thereof per acre. Inasmuch, however, as there are two crop seasons in each calendar year in India, in which the crops grown may differ widely in their water requirements, it naturally follows that in India the crop irrigated rather than the area of land served is emphasized. In this country, on the contrary, two crops are seldom grown on the same land in any one year and in consequence the duty of water is usually expressed as one cubic foot per second, abbreviated to one second-foot, to a certain number of acres which it irrigates.

Interpretation in the Western United States Neglects Crop Value

The opinion of many of the irrigation authorities in the Western United States has been sought as regards their definition and their interpretation of the term "duty of water."

From New Mexico, Bloodgood (2), offers this definition:

> Duty of water may be expressed as the number of acres of land that may be irrigated by a definite quantity of water, usually one cubic foot of water per second flowing continuously throughout the irrigation season; or as a certain quantity of water required to irrigate an acre of land, or in terms of total quantity of water used during an irrigation season. It is said to be high when a given quantity of water serves a large acreage, and low when it serves a small acreage.

and then he enumerates the following variable factors which tend to increase or decrease the duty of water:

(1) Kind and variety of crops.
(2) Method of delivery.
(3) Kind of distribution system.
(4) Preparation of the land surface.
(5) Method of application.
(6) Cultivation.
(7) Amount of water per irrigation.
(8) Economy and skill of user.
(9) Soil fertility.
(10) Climate—temperature, wind and rainfall.

From Colorado, Parshall (10), writes:

It is next to impossible to correlate the idea of duty of water for all conditions so that direct comparisons may be had. It will be appreciated that what might be the actual usage of water for one locality and particular crop, may not be that obtained for some other place with unlike physical conditions, but for the same crop.

To present the idea of duty of water various limitations have been imposed for the purpose of conveying a new thought. In some cases this has led only to confusion and uncertainty; however, all involving the fundamental conception of area to amount used. . . .

I do not think that the general conception of the idea of duty of water carries with it the element of least, economic, or best use of water. It will be noted that some authors seem to lend the impression that it is the least amount of water which will produce a given yield. This relation might be compared to the gasoline mileage of automobiles. The car that makes the most miles per gallon of fuel cannot be set up as the standard of comparison, because type of motor, weight of car, convenience of equipment, roads, length of journey and various other factors must needs be considered before any correlation would be possible. So with the idea of duty of water; many factors are involved, and it is, therefore, to be considered only from a general viewpoint.

I would conclude, therefore, that the expression "duty of water" be defined in its most general sense as that of area in acres irrigated by a continuous flow of one second-foot of water.

Different Examples of Duty of Water Show Area Basis

The following definitions of duty of water by House (6), also of Colorado, are confirmed by such authorities as Etcheverry (3), Widtsoe (14), Fortier (5), Winsor (16), Mead (8), Merriman (9), and Wilson (15):

Answering your question concerning a definition for the "duty of water," will say—by "duty of water" we mean the *service* that it will render when used for irrigation purposes. "Duty of water" is usually expressed in one of two ways:

First, the amount of land that a unit flow of water will irrigate; said flow to continue throughout the entire irrigation season. The unit flow of water used is the second-foot and the amount of land is expressed in acres. Hence the "duty" is expressed in *acres per second-foot.*

Second, the amount of water necessary to irrigate and produce crops on a unit of land. The unit of land is the acre and the amount of water is usually expressed in *acre-feet per acre* or in acre-inches per acre, and represents the total amount of water applied to that land throughout the entire irrigation season.

In Arizona, Smith (11), states:

With regard to the term "duty of water" a broad definition would be—the relation between water supply and area of land served. This relationship has been stated in a great many different ways, sometimes as the quantity of steady flow in the supply ditch and sometimes as the total depth per annum. Furthermore, the term is used by some writers to include the canal losses and by others to exclude the canal losses. In the first case it should be specified as the duty of water at the diversion point, and in the second case, the duty of water at the land, or at the farmers' headgate. I might go further and say that there is a duty of water as actually practiced (and that is very variable) and there is also the duty of water that is idealized by irrigationists in which the losses are reduced to a minimum.

In Wyoming, Fitterer (4), gives examples which corroborate the above ideas:

Concerning the definition of duty of water I think of the same in two ways, one as a so-called static unit, and the other as a kinetic unit—that is, water either at rest or water on motion. In the *former* consideration we usually regard the duty of water in Wyoming as

about 2 feet, which of course means a seasonal covering of 2 feet vertically over the area in question necessary to mature an ordinary crop. This, it is true, is a variable quantity depending upon the crop raised, the particular season, etc., etc. In the *latter* method of measurement, we gauge the duty of water in terms of cubic feet per second flowing throughout the growing season necessary to mature an ordinary crop. Our state laws allow 1 cubic foot per second to every 70 acres, and when filings are made they are rated on this basis. This is very liberal under our climatic conditions. Our altitude is quite high for most of the state of Wyoming, and the seasons correspondingly short and the summer fairly cool. Again this method of expressing the duty of water is more or less variable, depending upon many factors.

In Utah, Israelsen (7), also points out:

It is common usage in Utah to speak of a duty of one second foot to 35 acres early during the season when water is plentiful. Later, during June, the duty is increased to one second foot for 50 acres. Still later, during July and August, the duty is increased sometimes as high as one second-foot for 100 acres.

The term duty is used also in a quantitative sense with respect to a month or entire irrigation season. For example: since one second foot running for a period of 30 days delivers approximately 60 acre feet, if this quantity were applied to 60 acres during the month of June, the duty would be said to be one acre foot per acre. Likewise, for the season it is common usage to express the duty of water as four acre feet per acre gross or three acre feet per acre net, provided 25% of the amount of water diverted from its natural source is lost in conveyance and distribution.

In California, Beckett (1), illustrates his definition as follows:

Concerning the term ''duty of water.'' This is an ambiguous term and its use has led to considerable confusion. However, as commonly used, it is supposed to express the relation between quantity of water used and area of land served. This necessitates the use of the terms ''gross'' and ''net'' duty, and is further complicated by the number of ways in which this relationship may be expressed. This form of expression varies in the different localities and under different systems, and may take any one of the following forms:

(1) Number of acres served by 1 cubic foot per second.

(2) Number of acres served by 1 miner's inch.

(3) Directly in acre-feet, or acre-inches per acre.

If (1) or (2) is used another complication is encountered in that in order to be reduced to figures comparable with other localities the length of irrigation season or period through which delivery is made must be stated or assumed. As an example of this our water right on the University Farm states that it is entitled to a ''delivery not to exceed 1 c.f.s. for each 120 acres irrigated.'' The number of acre-feet to which we are entitled depends upon the number of days constituting the irrigation season, and since this is not designated there is sometimes quite a difference of opinion as to the quantity which should be delivered.

An example of the use of this form may be found in the statement that the average gross duty of water for rice in Sacramento Valley is 1 c.f.s. per 40 acres, the net duty being 1 c.f.s. per 60 acres.

If we are to continue to use the term duty of water, we believe it should be expressed directly in acre-feet or acre-inches per acre, and we are using only these terms in reporting results of experimental work.

Modifications Are Necessary

Those engaged in irrigation recognize that it is often necessary to be more explicit and modify the term "duty of water," using:

(1) Gross duty;

(2) Headgate duty;

(3) Net duty;
(4) Economic duty;
(5) Seasonal duty.

The fine points are very clearly stated by Wadsworth (13), so as to be easily understood by the plantation man:

In reply to your questions with regard to the definition of the term "duty of water" I am glad to give you our opinion of the meaning of the term, but I am fully aware of the fact that the words are used in a wide variety of meanings. Because of this indefiniteness of expression we have coined four or five terms, each one dealing with a certain phase of duty of water investigations.

By gross duty of water we mean the ratio existing between the quantity of water diverted by a main canal and the area of the land served by that canal. If a canal company reports a gross duty of water of 4 acre-feet per acre it is understood that enough water passes the intake of this canal during the irrigation season to cover the irrigated area to a depth of 4 feet. There is evidently no indication of crop responses in this definition and no intimation that better yields might not be secured with a higher or a lower gross duty of water.

By net duty of water we mean that ratio existing between the quantity of water delivered to an individual's headgate to the area of land irrigated by that individual. The net duty is always higher than the gross duty inasmuch as conveyance losses are included in the latter. We have another unit of duty of water which has never received a satisfactory name. This unit expresses the relation between surface applications and area which results in the greatest crop return. This may be quite different from either of the units mentioned above. A canal company may exhibit a gross duty of 5 acre-feet per acre, an individual might use 3 acre-feet per acre, but with careful analysis in view of his particular soil type and other local conditions it might be demonstrated that he could secure a greater yield with 2 acre-feet per acre. As I say, there is no satisfactory name as yet for the application of water which will secure the greatest crop production.

It is not at all sure that the application of water which will result in greatest yield in tons per acre will be the application which would result in the greatest net profit in dollars per acre. In cases where water is costly and the yield resulting from an additional application of irrigation water is insignificant the lower application might be the application resulting in greatest net profit while the larger would result in greatest tonnage. So we have a unit called the *economic* duty of water, which is again a ratio between a quantity of water and an area of land, this application being the one which produces greatest net income to the grower. You will, of course, see that all factors entering into the cost analysis of a certain crop must be considered in the determination of this unit.

Winsor (16), differentiates between net duty and what he calls headgate duty:

In general I understand "duty of water" to mean the ratio between volume of water used and unit area of land served. We speak, for example, of: a duty of 6 acre-feet per acre, or 15 acre-inches per season, or 70 acres per second-foot. In the first two cases we have the ratio expressed in volume of water per unit of land served. In the last case we speak of the area served by a given stream of water, without reference to any time limit.

We are more explicit when we speak of "gross duty," "headgate duty," or "net duty." The first two terms used here are plain enough, the gross duty being the volume measured at its source divided by the total area of irrigable land served; and in the second case the volume measured at the headgate of the farm, divided by the total area served. The result is stated in terms of unit volume per unit area irrigable. There is, however, much confusion in the use of the term "net duty." Some authorities refer to net duty as the volume of water used per acre after deducting losses in transit. In my opinion this use is incorrect and really is more properly the *headgate duty*. Net duty, as I understand it, is the amount of water which is taken up by the soil in the process of irrigating any particular unit area of crop, i.e., the headgate volume less the surface runoff divided by the area served. This

does not take into account the rainfall nor the loss through deep percolation. Furthermore, in this meaning of net duty, moisture from rainfall is not taken into account, nor is loss of water through deep percolation deducted. The term applies to the amount of water actually absorbed by the soil.

It is doubtful whether we in Hawaii need to consider this technical point.

Unanimous Dissatisfaction With Term "Duty of Water"

No one who was consulted was satisfied with the term "duty of water." How it originated has been touched upon by Fortier (5), who further comments as to why we continue to use it.

The state administrative officer, charged with the duty of allocating the public waters within his jurisdiction to those entitled to its use, is guided mainly by what courts and other tribunals have determined to be the duty of water for defined areas of land. As these determinations have been expressed for the most part as a unit of flowing water (a miner's inch or cubic foot per second) for a certain number of acres he naturally makes use of the same terms in apportioning the flow of a stream. Likewise the engineer who designs and constructs irrigation works is mainly concerned with the conveyance of given quantities of water from the point of diversion to the place of use, and for him the cubic foot per second or second-foot is the most convenient unit to adopt.

The farmer, on the other hand, is concerned with another phase of irrigation. His main object is to grow a profitable crop, and under arid and semi-arid conditions water is the main element in achieving this end. He therefore desires an adequate supply of water for his crops to meet each varying stage of their growth.

The farmer has never taken kindly to the term duty of water. He has no objection to the word ''duty'' being applied to a machine, but just why it should be applied to the quantity of water passing through his delivery box is not apparent to him. This has puzzled many who are not farmers.

To force an engineering term on the agriculturist, which is meaningless to him, is not wise unless the engineering features are of greater importance. In the case of irrigation the importance of the agricultural phase greatly surpasses the engineering. Engineering works are simply means to an end. They are usually the products of a few months' work by nomad engineers who are here today and gone tomorrow. On the other hand, the man who raises crops is usually pretty well rooted to the soil and must carry on year after year.

Wadsworth (13), at Davis, also objects to its use.

In my opinion the use of the term duty of water and its incorporation into literature is extremely unfortunate. I have often suggested to Professor Adams that we abandon its use and talk of something a little more concrete in its meaning. In his opinion the words are too deeply rooted in irrigation literature to ever get rid of them. My principle objection to the word duty in this connection is that it implies maximum achievement, whereas it is simply a measure of existing practice. You will, of course, appreciate that a high duty as we understand it means a relatively small application in terms of acre-feet per acre. I presume the philosophy is that in such a case water is working hard and a little of it goes a long way. At first glance it seems inconsistent, however, to be told that a duty of water of 2 acre-feet per acre is a higher duty than 3 acre-feet per acre. However, such is the commonly accepted meaning of the term.

Winsor (16), writes:

Frankly, it is my opinion that the whole terminology in irrigation practice should be subjected to a thorough overhauling, and should have ambiguities removed and terms added where necessary, and eliminated where uncertain or unnecessary.

Veihmeyer (12), is willing to discard the term duty of water in favor of "use of water."

I have felt that the use of this term (duty of water) is not entirely satisfactory, and I see no advantage in its use over that of such expressions as the ''use of water.'' For instance, the ''use of water under the canal system'' which would be comparable to gross duty and ''use of water on the individual farm'' in the same sense that net duty is now used.

Constructive Criticism Suggests Better Phrases

If the term duty of water is unsatisfactory, one must find a term which will meet the needs of the agriculturist and irrigation overseer; that will be simple and easily understood by the non-technical man. The following terms should be applicable to Hawaiian irrigation practice:

(1) Water requirements;
(2) Irrigation requirements;
(3) Use of water;
(4) Consumptive use of water.

Duty of water, in the accepted usage, implies actual use of the water in practice rather than the actual need of the plant. The definitions of the first two terms have been formulated by Fortier (5), bearing in mind the crop grown is paramount in all irrigation studies:

The term ''water requirement'' of sugar cane is the quantity of water including the effective natural precipitation and available soil moisture required for profitable crop yield at each stage of growth from the time of planting to harvesting under the physical and normal climatic conditions of the locality.

A definition of the term ''irrigation requirement'' might be expressed somewhat similarly, with this difference, however, that it would exclude effective precipitation and soil moisture, but be dependent upon both as well as upon the character of the soil and other physical and climatic conditions. It might be worded in some such way as this:

The term ''irrigation requirement'' of sugar cane is the quantity of water required to supplement at the right time the natural precipitation and ground water in such a way to produce satisfactory yields.

The requirements of the cane for water are not always met under variable weather conditions, and it is recommended that as agriculturists we refer to the "use of water" instead of the duty of water. We will have data on the "net use of water" when the amount of water applied to the fields has had deducted all transmission losses between the headgates and field intake. Gross use will be defined as the total amount of water pumped or supplied the plantation from mountain streams measured at the source. The ratio of water to the weight of the crop and to the area covered can be expressed without complications, and the confusions as to what is meant by a low or high duty will be obviated. There will be an economic use of water (on an acre and per ton sugar basis) dependent on the many factors of cost of production and returns from sale of the crop.

In the western United States, where soil moisture studies are made, the term "consumptive use of water" is finding favor. As yet we have no data in Hawaii which would give the consumptive use of water for sugar cane, but one should be familiar with this term when literature mentions it. According to Israelsen (7), "the consumptive use" is defined and interpreted as follows:

The consumptive use, is the amount of water in acre-feet per cropped acre per year absorbed by the crop and transpired or used directly in the building of plant tissue, together with that evaporated from the crop-producing land.

The direct source of "consumed" water is the water in the soil in any form so that crops can absorb it. The indirect sources of "consumed" water are those parts of the natural precipitation and of irrigation water which are stored in the soil in such depths and for such time as to permit absorption by crop roots together with such water as may be obtained by the crop roots from the water table. The consumptive use as here defined is, therefore, equal to the total evapo-transpiration.

It is a theoretical figure that cannot be obtained in field trials, as the investigator must have an elaborate equipment of tanks to determine the water actually used in the physiological process of the plant.

Conclusion

There is a decided tendency among modern irrigation investigators to have a rational terminology that can be understood by all. To accomplish this end the ambiguous term "duty of water" brought to America from India by engineers can be eliminated. "Use of Water" and "Water and Irrigation Requirements," are phrases that express much more plainly to the field man of today the relationship of water to his land and crops.. Before we are still further misled and our recent investigations in Hawaii are published, it will be a progressive move if the plantation men forget the term "duty of water," which is often misused and leads to confusion, and adopt a nomenclature which is simple and clear cut.

Acknowledgment

The assistance rendered in collecting the information presented in this report by those who have made "Irrigation" their life work is greatly appreciated, and the writer wishes to take this opportunity to thank all who contributed in defining and interpreting the term, "Duty of Water."

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Sugar Cane Mosaic and Insects

By Fred C. Hadden

Introduction

This paper deals with the entomological aspect, in Hawaii, of the relationship between insects and mosaic diseases, emphasizing the part played by the corn aphis, *Aphis maidis* Fitch, as a carrier of the disease, as established by Brandes and confirmed by Kunkel and others. The writer wishes to express his thanks to Otto H. Swezey for helpful suggestions; also to H. Atherton Lee for advice and for aid in determining grasses. This work has been carried on between the dates August 1, 1925, and May 9, 1927.

The purpose of the work was to answer the following questions:

1. What insects transmit cane mosaic?
2. What is the life history of the corn aphis, and its rate of reproduction in Hawaii?
3. What grasses serve as favorable hosts for aphis?
4. What grasses are a source of mosaic infection, and to which grasses can mosaic be transmitted?
5. Do winged and/or wingless aphis transmit mosaic?
6. What are the actions of aphis when transferred to new hosts?
7. What are the death factors of aphis?
8. How can mosaic be reduced?

Mosaic characteristics have been described by other authors, namely, Brandes (1), Lyon (8), Kunkel (6), and Stahl (7); and nearly every one has observed mosaic on sugar cane, bristly foxtail, and corn; therefore, it is not necessary to give in this paper a detailed description of the effect of the disease on grasses.

But attention should be called to the fact that different species and varieties of grasses appear quite differently when affected by the disease. For example, in certain varieties of sugar cane (8) the mottling is fine and the elongate light colored areas are small; in other varieties the light colored areas are large and long, giving a streaky appearance to the leaf. In the same variety of corn both the fine type and the striping may occur. This may indicate that the same kind of mosaic may take on a different form (appearance) on different hosts; or there may be more than one kind of mosaic on these hosts.

In these experiments no attempt was made to determine if there is more than one kind of mosaic. In the future experiments will be conducted to prove the presence of one or more kinds of mosaic in corn and other grasses.

Stahl (7) has proven that in Cuba corn stripe is transmitted by the corn leaf-hopper and that sugar cane mosaic is transmitted by the corn aphis. It will be interesting to discover if the same thing occurs in Hawaii.

It has been definitely proved that insect vectors are the main cause for the spread of mosaic diseases in a number of Dicotyledons. But these diseases are often easily transmitted artificially by needle punctures, grafting, and hypodermic injections. Sugar cane mosaic, on the other hand, is transmitted artificially only with great difficulty.

No organism has ever been found to cause mosaic, or at least it has never been recognized as the causative agent. For this reason the disease is said to be due to a filterable virus, meaning, that it is impossible to filter out the material from a solution causing the disease. The only thing we are sure of is the effect of the disease on the leaves which results in a mottling or streaking (striping) of the leaves, the affected area being lighter in color than the normal green of the leaf. This is due to the action of the virus reducing the amount of chlorophyll in the affected areas, forming a chlorotic condition. The clearness or distinctness of diseased plants varies considerably; later, on the same plant it is impossible to decide whether it is really diseased or not. This is true of sugar cane, corn and sorghum. Fertilizing with ammonium sulphate usually results in the disease becoming very distinct within a week.

Experimental Methods

Experiments were conducted on large tables upholding 50 to 60 8-inch pots, or 30 to 40 12-inch pots. The legs of these tables were placed in pans of water to prevent ants and cockroaches from interfering with the experiments. Insect-proof cages were made from large glass lantern globes and heavy wire screen cylinders. These were covered with a fine grade of cheese cloth. Except in a few cases these cages covered the plants experimented with until a few days before the end of the experiment; they were then removed and the plants were sprayed, to kill any remaining insects, and fertilized to bring out indications of mosaic. These cages were entirely insect-proof, as shown by examination with a binocular and the fact that no checks became infested with aphis or mosaic.

During the first six months, only seedlings of sugar cane and grasses were used, but later these could not be obtained, so Striped Tip and Yellow Tip seed pieces

from Manoa substation were used. Since only one check out of 200 became mosaic it may be presumed that all such seed was healthy and free from mosaic. Only cane experimented upon with mosaic-infested aphis ever became diseased.

The evidence developed in these experiments indicates that sugar cane mosaic is the same as the mosaic found on nearly all the other grasses in Hawaii, or at least they are all various forms of the same disease. This point is upheld by the fact that the disease is readily transmitted back and forth between several of these grasses.

Experiments With Insect Vectors

Two insects have transmitted the disease: the corn aphis from various grasses to cane and other grasses; and the corn leafhopper, *Peregrinus maidis* (Ashm.), from corn to corn and in one case from corn to Striped Tip cane.

The following insects have repeatedly failed to carry or transmit mosaic from mosaic plants to healthy ones:

1. Sugar cane aphis—*Aphis sacchari* Zehnt.
2. Sugar cane leafhopper—*Perkinsiella saccharicida* Kirk.
3. Grass leafhopper—*Stictocephala festina* (Say).
4. The Blue (or green) Sharpshooter—*Draeculacephala mollipes* (Say).
5. Sugar cane leafmite—*Tetranychus exsiccator* Zehnt.

Life History of the Corn Aphis

An idea of the rapid growth and multiplication of the corn aphis from one female are indicated by the following data and discussion:

Date	Number of Aphis
August 26, 1925	1
August 27, 1925	2
August 28, 1925	3
August 29, 1925	4
August 31, 1925	6
September 1, 1925	9
September 3, 1925	13
September 5, 1925	27
September 9, 1925	67
September 14, 1925	223
September 17, 1925	371

These data were taken from Pot 6, dwarf evergreen broom corn. The plants were seedlings, two inches high with three leaves, at the beginning of the experiments. Later the aphis became so numerous that the plants became smutty and finally died.

The aphis first placed on the plants was full-grown and producing young when it was removed from Pot 4, dwarf evergreen broom corn. It produced one young every day up to September 1, when it died. At this time its first offspring had produced two young. By September 5, all the old adult's offsprings were reproducing. On the 14th of September, the third generation was reproducing,

and this accounts for the increase in count from 223 to 371. It was only during this late stage that the aphis became numerous enough to be really noticeable, and it seemed as though they had sprung into being overnight. Sometimes a single aphis may produce two or even three young a day, if conditions are favorable; i. e., warm and not too humid. Along about the fourth or fifth generation, winged forms appear. It is these winged forms that are more apt to carry mosaic because they have a rapid means of transportation on air currents.

Ten days after an aphis is born it begins to reproduce, and it may produce from one to two young every day for twenty days. In the meantime the second generation begins to reproduce, and by the end of thirty days the third generation are reproducing; so in a very short time the number of descendants from one aphis is enormous. In two months the offspring of one aphis would be over 1,000,000, provided conditions were suitable and that each aphis lived thirty days. However, this rapidity of reproduction is only approached upon sorghum, corn, and Sudan grass, never on any of the other grasses.

Hosts of the Corn Aphis

The corn aphis has been found reproducing (either in the field or in experiments) upon the following grasses:

1. *Panicum torridum* Gaud.—Hairy panicum grass.
2. *Panicum barbinode* Trin.—Para grass.
3. *Panicum maximum* Jacq.—Guinea grass.
4. **Holcus sorghum* L.—Sorghum.
5. **Holcus sudanensis* (Piper)—Sudan grass.
6. *Holcus sorghum* var.—Broom corn.
7. *Holcus sorghum* var.—Dwarf Evergreen Broom Corn.
8. *Zea mays* L.—Sweet or ear corn.
9. **Chaetochloa verticillata* (L.)—Bristly foxtail grass.
10. **Cenchrus hillebrandianus* Htch.—Burr grass.
11. *Syntherisma chinensis* (Nees).
12. *Syntherisma sanguinalis* (L.)—Crab grass.
13. *Syntherisma pruriens* (Trin.)—Pig grass.
14. *Eragrostis cilianensis* (All.)—Stink grass.
15. *Valota insularis* (L.)—Chase grass.
16. *Chloris paraguayensis* Steud. (Sw.).
17. *Chloris radiata* (L.).
18. *Eleusine indica* (L.)—Goose grass.
19. *Tricholaena rosea* Nees—Red top.
20. *Paspalum orbiculare* Forst.
21. *Paspalum fimbriatum* H. B. K.
22. *Saccharum officinarum* L.—Sugar cane.
23. **Echinochloa colonum* (L.)—Paddy grass.
24. *Echinochloa crusgalli crus-pavonis* (H. B. K.).
25. *Hordeum vulgare* L.—Barley.

26. *Avena sativa* L.—Oats.
27. *Triticum aestivum* L.—Wheat.
28. *Oryza sativa* L.—Rice.
29. *Capriola dactylon* (L.)—Bermuda grass.
30. **Holcus halepensis* L.—Johnson grass.
31. *Coix lachryma-jobi* L.—Job's tears.
32. *Dactyloctenium aegyptium* (L.).
33. *Sporobolus diander* (Ritz.).
34. *Heteropogon contortus* (L.)—Pili grass.

Those with asterisk were found to be most commonly infested with aphis. Bristly foxtail grass, the most widespread grass on Oahu, was usually found to have both mosaic and aphis. Aphis were never found to be numerous on foxtail, and at times it was very difficult to find this grass with either aphis or mosaic, or both.

Transmission of Mosaic Disease

Transmission of mosaic to cane more than two months old is very difficult and can usually be accomplished only after the cane has been heavily cut back, exposing the tender inner leaves of the spindle to the proboscis of the aphis.

At first young seedlings of grasses and cane were used; later, seed pieces of Striped Tip and Yellow Tip. The seed was carefully selected from cane growing in the Manoa substation. That this cane was free from mosaic was shown by the fact that, with only one exception, all seed from this source produced healthy, non-diseased plants unless experimented upon with mosaic-infected corn aphis.

So far, I have been unable to transmit mosaic from cane to any other grasses owing to difficulties in raising non-mosaic-infested corn aphis on mosaic cane.

At first the resistant Hawaiian-grown corn seed was used, but the results were unsatisfactory because this corn did not show mosaic characters distinctly. Later Golden Bantam seed was procured from the States, and this proved very satisfactory, as it showed very clearly mosaic markings.

Mosaic has been transmitted experimentally as indicated by the following table which shows: the number of the pot or cage experimented upon, the grass from which aphis vectors were taken, the plants becoming infected, the vector, the time period between the transfer of the vector from the mosaic to the healthy plants, and the appearance of the disease on the new host.

1927 EXPERIMENTS

Pot No.	Source of disease		Infected plant	Vector	Time period
8	Corn	to	Striped Tip	20 corn leafhoppers	19 days
10	Sorghum	to	Striped Tip	100 aphis	54 days
12	Sorghum	to	Striped Tip	500 aphis	19 days
14	Sorghum	to	Striped Tip	300 aphis	36 days
16	Sorghum	to	Striped Tip	200 aphis	19 days
18	Sudan	to	Striped Tip	50 aphis	32 days
22	Sorghum	to	Striped Tip	300 aphis	18 days

24	Sorghum	to	Striped Tip	200 aphis	18 days
30	Foxtail	to	Striped Tip	30 aphis	9 days
32	Foxtail	to	Striped Tip	60 aphis	32 days
33	Foxtail	to	Striped Tip	30 aphis	14 days
34	Foxtail	to	Striped Tip	30 aphis	9 days
35	Foxtail	to	Striped Tip	30 aphis	9 days
37	Foxtail	to	Striped Tip	30 aphis	9 days
38	Foxtail	to	Striped Tip	30 aphis	9 days
400	Corn	to	Corn	1 adult corn leafhopper	34 days
402	Corn	to	Corn	3 corn leafhoppers	17 days
404	Corn	to	Corn	12 corn leafhoppers	17 days
405	Corn	to	Corn	14 corn leafhopper nymphs	17 days
409	Corn	to	Corn	10 corn leafhopper nymphs	31 days
422a	Foxtail	to	Sorghum	20 corn aphis	20 days
423a	Foxtail	to	Foxtail	20 corn aphis	20 days

1925-26 EXPERIMENTS

Pot No.	Source of disease		Infected plant	Vector	Time period
46a	Sorghum	to	*Syntherisma chinensis*	30 corn aphis	77 days
65	Foxtail	to	Foxtail	15 corn aphis	12 days
124	Sorghum	to	ST x H109	40 corn aphis	31 days
140	Foxtail	to	YT x H109	50 corn aphis	22 days
141	Corn	to	OP26 x ST.H109	10 corn aphis	24 days
143	Foxtail	to	OP5YT x H109	30 corn aphis	19 days
144	Foxtail	to	OP5YT x H109	30 corn aphis	11 days
147	Foxtail	to	OP6ST x H109	35 corn aphis	27 days
149	Sorghum	to	OP5YT x H109	200 corn aphis	14 days
184	Crab grass	to	OP6ST x H109	25 wingless corn aphis	18 days
205	Sorghum	to	*Syntherisma chinensis*	200 wingless corn aphis	67 days
219	Sorghum	to	Chase	200 corn aphis	57 days
225	Foxtail	to	Corn	15 corn aphis	42 days
229	Sorghum	to	Corn	30 corn aphis	28 days
232	Foxtail	to	Foxtail	18 corn aphis	77 days
233	Sorghum	to	Foxtail	340 corn aphis	74 days
235	Sorghum	to	Sorghum	30 corn aphis	50 days
243	Foxtail	to	Foxtail	*Needle punctures*	41 days
243d	Foxtail	to	Foxtail	*Needle punctures*	19 days
243b	Sorghum	to	Foxtail	30 winged corn aphis	101 days
254f	Corn	to	Corn	12 corn leafhoppers	37 days
258d	Sorghum	to	Foxtail	20 corn aphis	13 days
258h	Sorghum	to	Foxtail	20 corn aphis	13 days
259b	Sorghum	to	Corn	60 corn aphis	13 days
260a	Sorghum	to	Corn	20 aphis	13 days
260d	Sorghum	to	Corn	20 aphis	13 days
260g	Sorghum	to	Corn	20 aphis	13 days
263a	Sorghum	to	Corn	45 aphis	20 days
263b	Sorghum	to	Corn	45 aphis	16 days
263c	Sorghum	to	Corn	45 aphis	11 days
264a	Sorghum	to	Sorghum	60 aphis	29 days
264b	Sorghum	to	Sorghum	50 aphis	25 days
300	Sudan	to	Striped Tip	20 aphis	38 days
301	Sudan	to	Striped Tip	20 aphis	38 days
303	Sudan	to	Striped Tip	20 aphis	38 days
306	Sudan	to	Striped Tip	10 aphis	40 days

307	Sudan	to	Striped Tip	24 aphis	40 days
309	Sorghum	to	Yellow Tip	15 aphis	45 days
311	Sorghum	to	Yellow Tip	15 aphis	45 days
316	Sorghum	to	Yellow Tip	15 aphis	45 days
320	Foxtail	to	Yellow Tip	10 aphis	32 days
322	Foxtail	to	Yellow Tip	10 aphis	32 days
325	Foxtail	to	Yellow Tip	? aphis	49 days
327	Sudan	to	Yellow Tip	? aphis	42 days
328	Sudan	to	Yellow Tip	? aphis	42 days
332	Sudan	to	Striped Tip	? aphis	42 days

At all times there was at least one check of the same kind near the plant experimented upon, and in many cases there were from two to three checks present. Throughout the entire period of these experiments only one check became mosaic.

Canes marked OP26 x ST.H109, OP5YT x H109, ST x H109, YT x H109, etc., were seedlings.

For every experiment that was a successful transmission there were at least three to five unsuccessful attempts, and in many cases twenty to thirty attempts at transmission were failures (this was during the hotter summer months). As many as 100 to 500 aphis were used in some of the experiments that were failures.

The experiments indicate that temperature and humidity are very important factors in the development and transmission of mosaic. In the warmer summer months it was very difficult to transmit the disease, but in the cooler winter months mosaic was more readily transmitted; but even under the latter conditions there were many unaccountable failures. The maximum temperature at which mosaic may be carried and developed is probably near the average temperature of our three coolest winter months.

Twenty-two different transmissions were made in these experiments; namely:

From Corn to Striped Tip, Corn, OP26 x ST.H109, and Foxtail.

From Sorghum to Striped Tip, *Syntherisma chinensis,* OP5ST x H109, Chase, Corn, Foxtail, Sorghum, and Yellow Tip.

From Foxtail to Striped Tip, Sorghum, Foxtail, YT x H109 (Seedling), OP5YT x H109, OP6ST x H109, Corn, and Yellow Tip.

From Crab grass to OP6ST x H109.

Possible Recovery of Diseased Plants

Three pots of mosaic sorghum were kept for over a year, March 26, 1926, to March 31, 1927, to find out if they would remain affected. They did so throughout this length of time. Sudan grass, H 109, Striped Tip, and Yellow Tip gave the same results. The distinctness or clearness of the mosaic streaks varied, being sometimes more distinct and sometimes scarcely perceptible. These plants were all repeatedly ratooned and fertilized. Four days after fertilization the plants greened up and the mosaic showed up distinctly.

These experiments indicate that the above plants do not grow out of a mosaic condition in Honolulu in the period of one year; probably they never do.

Grasses Affected With Mosaic Disease

The following grasses have been found with mosaic and may be a source of infection:

1. Corn. Commonly.
2. Dwarf Evergreen Broom Corn.
3. Evergreen Broom Corn.
4. Sorghum. Commonly.
5. Bristly Foxtail. Commonly.
6. Para grass—*Panicum barbinode*. Rarely.
7. Pig grass—*Syntherisma pruriens*. Occasionally.
8. Sudan grass.
9. Hono Hono grass—not a grass.
10. *Syntherisma chinensis* (Nees). Occasionally.
11. Sugar cane—*Saccharum officinarum* L.
12. *Echinochloa* sp. at the Hind-Clarke Dairy.
13. Job's Tears—Coix lachryma-jobi L.
14. Crab grass—*Syntherisma sanguinalis* (L.).
15. *Valota insularis*—Chase.
16. Hilo grass—*Paspalum conjugatum* (L.).
17. *Sporobolus diander* (Ritz.).

The most commonly found and widespread grasses with mosaic were foxtail, corn, sorghum, Sudan, sugar cane, pig grass, crab grass, and *Syntherisma chinensis*.

Observations on the Actions of the Corn Aphis

Four aphis were placed on a clean horizontal blackboard. Their original position was marked with a piece of chalk, and their trails were followed by drawing the chalk along behind them. The general direction of the trails of all four aphis was towards the window, near which they were placed. The following table shows how far the aphis traveled as measured along their trails, the time consumed, and the straight distance between starting point and finish:

Aphis No.	Size	Trail distance	Distance in straight line	Time
1	¾ grown	30 ins.	24 ins.	1 hr.
2	¾ grown	36 ins.	27 ins.	4 hrs.
3	½ grown	8 ins.	6 ins.	4½ hrs.
4	Full-grown adult	40 ins.	30 ins.	4½ hrs.

All four aphis were wingless and healthy and were not injured in being transferred from the sorghum by the camel's hair brush. At times they had difficulty in crossing the chalk marks. This experiment was twice repeated with similar results; it indicates how far aphis may travel under the most favorable conditions on a smooth surface. When the conditions are changed but slightly, the aphis are hopelessly lost and may not travel more than two inches in as many hours. This is especially true if the ground is slightly dusty, plowed, cultivated, rough, or gravelly. Only on the smoothest ground can aphis travel any appreciable distance,

and then with great difficulty. Thus it seems most improbable that wingless aphis may crawl from mosaic grasses which have been cut down onto cane and infect it; the chances are, in fact, very remote, because they encounter even greater difficulties when they enter the stiff, spiny hairs on the leaf sheaths of H 109 and many of the other varieties.

It is only from the winged forms that real danger is to be expected, and these are probably the main vectors of the disease for the following reasons:

1. They are produced by the drying up of the host, and
2. By the ripening of the host as the seeds are produced.
3. Another factor at this time is the loss of protection in the curled-up terminal leaves of plants going to seed.

In the field, grasses which are weeds are generally left until they go to seed before they are cut down. By this time the aphis on these grasses have developed into winged forms and have deserted the drying host, flying to sugar cane and other grasses.

These experiments indicate that mosaic is more readily transmitted to cane under two months old, either ratoon, seed piece, or seedling, and especially to plants which have had the central spindle cut off short so that the young light green or yellow, tender inner leaves are forced out by the growth of the cane and are exposed to the attacks of these aphis. It is usually in younger cane that weeding is necessary, and as some of the cane is always cut at the same time, ideal conditions for the transmission of mosaic by aphis are produced. This brings out the point that grasses which are weeds should be cut when small, before they go to seed and before they begin to dry up; and care should be taken not to cut the cane at the same time.

Corn aphis were transferred from grass hosts of one species and placed on other species, carefully watched under the binocular microscope and their actions noted. Some of the transfers thus made and observed were from corn to cane, sorghum, Sudan, and bristly foxtail; and from various grasses to cane. In nearly every case the aphis crawled around on the new host plant until a suitable place was found to feed. While crawling, the aphis holds the body at some distance from the host plant, stopping occasionally to insert the proboscis. Six or seven trials are usually attempted before the final deep insertion (½-1 mm.) of the beak is made for feeding. It is easy to see when the aphis commence feeding, for they then lie close to the host plant, in fact against it, and a pumping motion becomes apparent.

In almost every experiment the aphis were feeding within five or ten minutes after transfer to the new host. They had greater difficulty in inserting the beak in older cane than in younger cane (under six weeks old), as shown by the fact that in younger cane they were usually feeding after only two or three attempts to insert their beaks; but on the older canes as many as eight or nine attempts were made before they could sink their proboscis into the tissues of the new host. The aphis wandered around much more on the older plants than on the younger, this evidently being due to the fact that they were encountering difficulties in locating a favorable place for feeding. There can be no doubt that the aphis encounter great

difficulty in inserting the proboscis in the harder (more siliconized) leaves of the older cane.

It is also certain that in some of the thicker leaved cane it would be impossible for aphis, especially corn aphis and any kind of young aphis, to reach the phloem from the upper surface; the distance from above is greater than the length of the proboscis, without taking into consideration the fact that the beak may not go straight into the phloem through the cells, but probably between the cells, following the intercellular spaces and the line of contact of two cell walls which may be weak and separate, allowing the beak to penetrate in this manner. Incidentally, aphis pierce the epidermis at random and may or may not make use of the stomata; they probably do so very rarely and then only accidentally.

Aphis settle down to feeding much sooner on young grasses than they do on older grasses, and young or old cane, even though they have been starved for a day or two.

A cross section of a cane leaf reveals other causes for the difficulties encountered by aphis in feeding. The vascular bundles of sugar cane are shown* to be composed of xylem and phloem surrounded by a starch sheath, and the starch sheath, in turn is surrounded by parenchymous tissue; next to this lie the cells rich in protoplasm, the giant cells, and then at intervals along the upper surface of the leaf, the motor cells which are also giant cells.

The xylem cells are above, towards the upper surface of the leaf, the phloem cells are under these, and above the xylem are stone cells, which are very hard and with contents high in silicon, making a mass impenetrable to the beaks of aphis.

Beneath, and more or less surrounding the phloem, are sclerenchyma cells. These are thick-walled cells, with their walls composed mainly of lignin. Underneath these may lie the starch sheath and perhaps a few parenchymous cells; then again under these is another group of stone cells, and next are the cells of the lower epidermis.

Aphis are mainly phloem feeders (4), and since most of the aphis feed upon the lower surface of the leaves, their beaks must penetrate through the lower epidermis and epidermal cells, or the stomata, then through the stone cells or, more likely, between bunches of stone cells, then consecutively through the following tissues: parenchyma, starch sheath, sclerenchyma, and finally into the phloem.

From the epidermis, epidermal hairs or spines may arise; and the aphis encounter difficulties in reaching the epidermis, or in moving around on the leaf, depending upon the size, thickness, and number of these hairs. H 109 is one of the varieties of cane which is more resistant to mosaic, and the fact that the leaves (especially the sheaths) are heavily covered with stiff, large hairs, may be the reason that it is so resistant; for the aphis become hopelessly lost and are unable to approach near enough to the epidermis to sink their beaks into the phloem.

Both the external and internal structure of a leaf show characters which may prevent aphis from inserting the beak and thus transmit mosaic, these characters are:

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* By N. A. Cobb, 1906, Bull. 4, Div. of Path. and Physio. of H. S. P. A. Exp. Sta.

1. Number, size (thickness), and hardness of leaf hairs.

2. Distance between the vascular bundles and their corresponding stone and sclerenchyma cells.

3. The size of the groups of stone and sclerenchyma cells.

4. The distance between the phloem and epidermis.

5. The thickness and hardness of the epidermis.

Death Factors of Aphis

Ladybeetles, syrphid flies, lacewing flies, predaceous mites, humidity and fungi, all tend to reduce aphids in number.

By far the most important of these is the Australian ladybeetle, *Coelophora inaequalis,* which preys, in both the adult and larval stages, on aphis. Fungi kill off large numbers of aphis in damp weather and are at such times the most important death factor. Any one of the above factors may be at certain times the most important; but they usually work together, and it is only a matter of time before they get the upper hand on any bad outbreak of aphis. In cases of very bad outbreaks of aphis on corn, sorghum, or very young cane (especially seedlings), the writer recommends the following spray to be applied with a knapsack sprayer under the highest pressure possible:

Black-leaf 40, or Nicotine Sulfate	1 to 2 teaspoonfuls
Liquid soap (or Sopozon)	1 tablespoonful
Water	1 gallon

Field methods have already been worked out for the prevention of mosaic and are known on all the plantations, especially with reference to healthy seed selection and control of weeds. However, I would like to refer again to the time when weeds should be cut; namely, while they are young and before they have a chance to flower or form seeds, and care should be taken not to cut the cane with the weeds.

By far the most important means of reducing mosaic is through planting healthy seed pieces and by keeping the fields free from grass weeds. The Australian ladybeetle certainly does its work well, even though at times it may be a little late. It might be advisable in the future to import more ladybeetles; but this is not the case at present, for the predators we now have in Hawaii are quite adequate to cope with the situation, except in a few rare cases.

Summary

1. The same kind of mosaic may look entirely different on various hosts, i.e., different species of grasses or sugar cane varieties (8).

2. Mosaic characteristics vary greatly within the same species and varieties, such as corn and sorghum.

3. Or, the same species and varieties of grasses may have more than one kind of mosaic.

4. Transmissions were made between twenty-two different species and varieties of grasses through the use of the corn aphis as a vector. The evidence developed in these experiments indicates that these twenty-two grasses acquired the same kind of mosaic, but with different characteristics. Or the aphis transmitted more than one kind of mosaic.

5. Mosaic was transmitted between corn plants by the corn leafhopper. In many cases attempts at transmission were failures.

6. Corn aphis may transmit one kind of mosaic (7).

7. Corn leafhoppers may transmit a different kind of mosaic (7).

8. Or both of these insects may transmit more than one kind of mosaic.

9. The corn leafhopper transmitted mosaic only from corn to corn with one exception, which was probably an accident.

10. Mosaic is transmitted most easily in the winter and the plants "show up with clear cut cases of mosaic."

11. In the summer it is more difficult to transmit mosaic and the mosaic characteristics are usually indistinct.

12. The experiments indicate that mosaic is permanent throughout the life of the plant, but that it may become very poorly defined at times, and later very pronounced.

13. No one knows the causative agent of mosaic, so it is called a filterable virus.

14. Wingless aphis have great difficulty in crawling any distance, except on a flat, smooth, dustless surface.

15. Winged aphis may fly with the wind for miles and therefore are probably the main agents in the spread of mosaic.

16. Both winged and wingless corn aphis and corn leafhoppers transmit mosaic.

17. Cane aphis do not transmit mosaic in experiments.

18. Mosaic may be transmitted artificially by hypodermic injections, needle punctures, grafting, etc., but only with great difficulty and many failures.

19. Better control of mosaic may be attained by cutting grasses when they are young, before they flower, and care should be taken not to cut the cane at the same time. The weeds cut should be piled as far from growing cane as possible. If possible cover the weed pile with fine dust.

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Glucose Determinations

By H. A. Cook and W. R. McAllep

Methods for the determination of reducing sugars are more varied and have been subject to more revision than probably any other method used in sugar laboratories. All of these methods are more or less empirical and most of them are subject to factors which may introduce considerable error in the results.

The method described by Eynon and Lane (1), using methylene blue as an internal indicator, is one of the most convenient methods that has come to the writers' attention. This method combines a high degree of accuracy with simplicity, rapidity and convenience.

This method was first extensively used in the Islands by H. W. Robbins at Oahu Sugar Company. The method with certain modifications and precautions, based on experience in this laboratory, has recently been described in *The Hawaiian Planters' Record* (2). The method with other minor modifications has been proposed for adoption as the official method of the Association of Hawaiian Sugar Technologists.

Before adopting the method in this laboratory it was thoroughly checked against known mixtures of glucose and sucrose of approximately the concentrations found in mill juices. This was done by both H. F. Bomonti and the senior author, and the method was found to give accurate results on these solutions. Since then it has been used in this laboratory extensively on juices in clarification and other investigations. The method has proved itself to be so satisfactory that it has been proposed as the official method of the Association.

Before bringing this proposal before the association it was found advisable to investigate a few points which had arisen in connection with the use of this method and which might affect the accuracy of the results secured by both this method and the regular Munson and Walker method. These questions resolved themselves largely to the manner of preparation of the sample before titration or treatment with the Soxhlet solution.

Preparation of Samples

The question of preparation of samples for analysis has received considerable study, but there still appears to be some conflicting opinion on the subject.

Clarification of Sample:

It is quite generally conceded that most sugar house products require clarification with neutral lead acetate to remove non-sugar reducing substances, although there appears some difference in opinion on this point. Meade and Harris (3) concluded from their experiments that lead acetate clarification was unnecessary in the products with which they were working. Norris and Brodie (4) working with Hawaiian molasses concluded that these products should be clarified with lead acetate.

The conclusion upon which the necessity of lead acetate clarification is based seems largely to rest upon the fact that higher results are secured if the reducing sugars are determined before clarification with lead acetate than are secured after clarification and subsequent removal of the lead. It had been the opinion of one of the writers that neutral lead acetate clarification was unnecessary. The only experimental data the writers were able to find which proved that the neutral lead acetate precipitate actually contained non-sugar reducing substances was that of Eynon and Lane (1). As there was no experimental evidence available to solve this question for Hawaiian products a series of tests were run to secure data on this point.

The effect of clarification with lead acetate was determined on six samples of final molasses so chosen as to represent different parts of the Islands and widely varying conditions of practice. Glucose was determined on these samples in two ways. Two portions of 10 grams each were weighed into 250 cc. flasks, and dissolved. The first portion made to volume, 50 cc. transferred to a 200 cc. flask, 10 cc. of 10 per cent potassium oxalate added, made to volume and filtered through Kieselguhr. The second portion was clarified with 3 cc. 54° Brix neutral lead acetate, and filtered. To 50 cc. of this filtrate in a 200 cc. flask, 10 cc. of 10 per cent potassium oxalate was added, made to volume and filtered. The final filtrates were used for the glucose determinations. Glucose was determined in triplicate. Potassium oxalate was used instead of disodium phosphate based on the conclusions of Eynon and Lane that lime salts gave low results. The results are as follows:

TABLE I

	Treatment		
Sample No.	Potassium Oxalate % Glucose	Lead Acetate Potassium Oxalate % Glucose	Difference
1	11.089	10.789	.300
2	12.938	12.596	.342
3	20.935	20.450	.385
4	23.568	22.917	.651
5	16.005	15.743	.262
6	16.949	16.548	.401
7	11.325	11.020	.303

These figures all show decidedly lower results after treatment with lead acetate.

It is generally considered that neutral lead acetate does not remove appreciable amounts of reducing sugars from solution. Browne (5) gives figures show-

ing comparative amounts. Eynon and Lane (1) show that the amount of reducing sugar removed by neutral lead acetate is negligible.

The following test was designed to determine whether the substances which are removed from molasses by neutral lead acetate have reducing power. A large quantity of three of the above samples was treated with neutral lead acetate and filtered. The precipitate was washed with distilled water until a test with alpha-naphthol showed no reaction for sugar and then washed with an additional 3 liters of distilled water. The precipitate was then suspended in water, decomposed with hydrogen sulphide, filtered, washed and reprecipitated with neutral lead acetate. This precipitate was again thoroughly washed, suspended in distilled water, decomposed with hydrogen sulphide the second time, filtered and washed. It was again precipitated with neutral lead acetate and thoroughly washed with distilled water. This treatment entirely eliminated all sugar from the lead acetate precipitate.

The sugar-free precipitates secured were treated in three ways. One portion was treated with hot distilled water and filtered; a part of this filtrate was deleaded with disodium phosphate and the other portion freed from lead with hydrogen sulphide and the excess removed by boiling. These portions were added to Soxhlet solution and heated under the conditions of the glucose determination. Copper was reduced in both cases. (2) Another portion of the lead acetate precipitate was dissolved with dilute sulphuric acid and the lead removed by boiling down with the acid. The filtrate from this treatment, neutralized with NaOH, also reduced Soxhlet solution. (3) A third portion of the lead acetate precipitate was decomposed with hydrogen sulphide, freed from the excess by boiling and this filtrate also reduced Soxhlet solution. The precipitates from the three molasses were treated in this manner and all reduced Soxhlet solution when treated as above. A portion of the filtrate which had been treated with sulphuric acid (No. 2 above) and then neutralized, was added to a solution containing equal parts of pure dextrose and levulose, and the reducing power was determined before and after the addition with the following results:

Dextrose-Levulose Solution	.1844 gms. reducing sugar.
Ditto, plus filtrate	.1880 " " "

No definite amount of the precipitated substance was added to the pure solution, so the reducing power of the substances was not calculated. The reducing power of the pure solution was materially increased by the presence of the substances which had been precipitated from molasses by the neutral lead. A portion of this mixed solution was again treated with neutral lead acetate, deleaded with disodium phosphate and the reducing power again determined. The result was .1848, which agreed very closely with the original figure. From these tests the following conclusions were drawn:

(1) Neutral lead acetate removes organic non-sugar reducing substances from molasses.

(2) The substances removed by neutral lead acetate and freed from sugars reduce Soxhlet solution in the absence of other reducing sugars and increase the reduction in a pure dextrose or levulose solution.

(3) When freed from lead and added to pure solutions of dextrose or levulose these substances can again be removed by lead acetate and the original reducing power of the solution restored.

(4) The reducing substances removed from molasses by neutral lead acetate are sufficient to materially affect the results in a glucose determination.

Effect of Lime Salts on Glucose Determination

Eynon and Lane (1) have demonstrated that the presence of lime salts in the solution to be tested caused low results. They recommend that potassium oxalate be used instead of disodium phosphate as a deleading and decalcifying agent. This is the first reference that could be found showing the influence of lime on glucose determinations. Mead and Harris (3) secured higher results when using potassium oxalate as did Norris and Brodie (4), but this difference was not attributed to the removal of lime salts; they concluded that the potassium oxalate had a reducing action on the Fehling or Soxhlet solution.

Several series of tests were made to determine the above points and to determine the effect of lime and its removal on the determination of reducing sugars.

Does Potassium Oxalate Reduce Fehling Solution:

It was first determined whether potassium oxalate added to the Soxhlet solution in varying amounts in the absence of sugars would reduce copper. Various concentrations of the salt, from .5 gram to 20 grams per 100 cc., were added to the mixed Soxhlet solution and treated under the conditions that would apply to the glucose determination. In no case could reduction of copper be detected.

Varying amounts of a 10 per cent solution of potassium oxalate were then added to solutions of pure dextrose and levulose to determine whether any difference in the reducing power could be determined. The results are listed below.

TABLE II

	cc. Potassium Oxalate Added						
	Blank	2	4	5	6	8	10
	Grams reducing sugar						
Dextrose...	.1866	.1868	.1869		.1867	.1864	.1864
Levulose...	.1951			.1952			.1948
Levulose...	.1932	.1931	.1933		.1931	.1934	.1933

The above results are all practically constant and within the limits of experimental error. They show no change in the reducing power of either pure dextrose or levulose. Disodium phosphate was used in the same manner and no change in reducing power could be detected.

It can be concluded that in pure solutions neither potassium oxalate nor disodium phosphate influence the results of the glucose determination.

Lime in Pure Solutions:

The effect of adding lime salts to pure solutions was determined. For these determinations pure solutions of cane sugar and hydrolized cane sugar, also pure solutions of dextrose and levulose were used.

The first solution was a mixture containing 2 grams pure cane sugar and approximately .22 gram invert sugar. The invert sugar was prepared by hydrolysis of pure cane sugar with hydrochloric acid and then neutralizing with sodium hydroxide. To aliquot portions of this mixture varying amounts of different lime salts were added. No definite amount of lime was striven for in these solutions nor was the amount determined except that the solutions of lime were saturated solutions. The result of this test is tabulated below.

TABLE III

Sample	Treatment	Grams Glucose Found	Grams Glucose Decrease
1	Pure sucrose and glucose blank	.223	....
2	" " " " 2½ cc. CaO	.217	.006
3	" " " " 5 cc. CaO	.209	.014
4	" " " " 10 cc. CaO	.202	.021
5	" " " " 25 cc. CaO	.196	.027
6	" " " " 2½ cc. $CaCl_2$	.221	.002
7	" " " " 5 cc. $CaCl_2$	.220	.003
8	" " " " 10 cc. $CaCl_2$	.216	.007
9	" " " " 25 cc. $CaCl_2$	.215	.008
10	" " " " 2½ cc. $CaSO_4$	.224	*.001
11	" " " " 5 cc. $CaSO_4$	.224	*.001
12	" " " " 10 cc. $CaSO_4$	.218	.005
13	" " " " 25 cc. $CaSO_4$	.212	.011
14	" " " " 2½ cc. $Ca_3(PO_4)_2$	.221	.002
15	" " " " 5 cc. $Ca_3(PO_4)_2$	.217	.006
16	" " " " 10 cc. "	.215	.008
17	" " " " 25 cc. "	.213	.010

In practically all cases the value found for glucose is depressed by increased amounts of lime. Similar results were secured with both dextrose and levulose solutions.

	No Lime	Lime Added	Decrease
Dextrose	.2001	.1981	.0020
Levulose	.1949	.1897	.0052

It is apparent that the presence of lime causes low results. Removal of lime with potassium oxalate was studied in another solution of sucrose and glucose. This solution contained approximately 4 grams of sucrose and .175 gram of glucose per 100 cc. This solution was divided into five portions. One portion was used as a blank, 25 cc. of each of the above lime solutions were added to the other portions of this solution. These portions were further divided and the glucose determined both in the presence of the lime salts and after treatment with 10 cc. of 10 per cent potassium oxalate.

* Indicates increase.

TABLE IV

Sample	Treatment	No Lime Present	With Lime Present	Difference Due to Lime Salts	Decalcified With Potassium Oxalate	Difference Between Original and Decalcified Portion
1	None	.176	....	......	....	......
2	CaO		.152	—.024	.173	—.003
3	$CaCl_2$		.169	—.007	.175	—.001
4	$CaSO_4$		.166	—.010	.173	—.003
5	Ca Phos.		.167	—.009	.175	—.001

A solution of pure dextrose and one of pure levulose was also prepared and treated in a similar manner.

TABLE V

	Blank	Lime Added	
	No Lime	Not Removed	$K_2C_2O_4$ Added
Dextrose..................	.2001	.1981	.1995
Levulose..................	.1949	.1897	.1947

All of these samples show the depressing effect due to the addition of lime. Treatment with potassium oxalate restored the reducing power to practically the original point.

The amount of lime in the above samples, except possibly those with the smaller amounts of calcium sulphate and calcium phosphate, was in excess of what would be found in sugar house products other than molasses. To approximate clarification practice aliquot portions of a juice were clarified by adding increasing amounts of milk of lime. The glucose was determined in these samples both before removing the lime and after treatment with potassium oxalate.

TABLE VI

	Per Cent Glucose		
pH of Cold Limed Juice	Untreated Sample	Treated With Potassium Oxalate	Difference
	%	%	
6.5	.188	.189	+.001
7.5	.187	.186	—.001
8.5	.187	.187	.000
9.5	.187	.187	.000

These results would indicate that the amount of lime present in this particular clarified juice was not sufficient to affect the results.

Another series was run to corroborate the above, Table VII. In this series the glucose was also determined by the regular Munson and Walker method, Table VIII. Four portions of a sample of raw juice were clarified at four different reactions. These samples were held at 100° C. for approximately three hours and the glucose was determined before and after heating. Table VII shows the effect of removing the lime salts both before and after heating.

TABLE VII

Methylene Blue Method

Sample	Lime Not Removed %	$K_2C_2O_4$ Treated %	Difference
1a	.754	.778	.024
1b	.939	.959	.020
2a	.675	.694	.019
2b	.787	.801	.014
3a	.748	.767	.019
3b	.768	.792	.024
4a	.767	.788	.021
4b	.749	.767	.018

The above figures show an appreciable and consistent difference between the untreated and the potassium oxalate treated portion. The portions treated with potassium oxalate gave results averaging .020 higher than the untreated portion.

In the following tabulation the figures are arranged to show a comparison of the results secured by using potassium oxalate in the methylene blue method with lead acetate and disodium phosphate in the Munson and Walker method. The Munson and Walker method was used conforming with the prescribed procedure of the official methods of the Association of Hawaiian Sugar Technologists, except that the amount of reduced copper was determined by titration with thio-cyanate solution rather than by weight as cupric or cuprous oxide. Titration with thio-cyanate has been shown to give more accurate results than the method of weighing.

TABLE VIII

Comparison of Results of Two Treatments

Sample	Potassium Oxalate No Lead Acetate % Glucose	Lead Acetate and Disodium Phosphate % Glucose	Difference
1a	.778	.725	.053
1b	.959	.912	.047
2a	.694	.648	.046
2b	.801	.766	.035
3a	.767	.723	.044
3b	.792	.745	.047
4a	.788	.745	.043
4b	.767	.726	.041

These figures show a very consistent difference in results between the two methods of treatment. The results given by the methylene blue method using potassium oxalate average .044 higher than those secured using disodium phosphate in the Munson and Walker method. Referring to the results in Table VII, it is noted that in determining glucose by the methylene blue method without lead acetate or potassium oxalate, the results average .025 higher than those secured by the Munson and Walker method, where lead acetate and disodium phosphate are used. Results which are shown later indicate that the above difference may be due to two factors. Lime which was not removed by the disodium phosphate undoubtedly accounts for a part of the difference, the lead acetate used in the

same procedure may remove reducing non-sugars and cause a part of the difference. Lead acetate was not used in conjunction with the potassium oxalate.

Another test was made to determine the respective amounts of lime removed by different methods of treatment. Four portions of a raw juice were clarified with increasing amounts of lime. Glucose was determined on each sample using the methylene blue method: first, with no treatment; second, adding 10 cc. of 10 per cent potassium oxalate; and third, clarifying with 3 cc. 54° Brix lead acetate and subsequent deleading, one portion with 10 cc. of 10 per cent disodium phosphate, and the other with 10 cc. of 10 per cent potassium oxalate. The CaO was determined on an ashed portion of each filtrate.

TABLE IX

	1		2		3		4	
Treatment	Glucose	CaO	Glucose	CaO	Glucose	CaO	Glucose	CaO
	%	%	%	%	%	%	%	%
None	.874	.0013	.877	.0020	.880	.0022	.880	.0023
Potassium Oxalate	.879	.0003	.888	.0003	.877	.00025	.892	.0004
Lead Acetate and Disodium Phosphate	.872	.00045	.874	.00035	.876	.0011	.882	.0021
Lead Acetate and Potassium Oxalate	.871	.00035	.879	.0002	.876	.0005	.888	.0009

With one exception, treatment with potassium oxalate alone gives the highest figure for glucose; also, with one exception, this treatment gives the greatest elimination of lime. The determination of glucose without any treatment gives a figure slightly lower than that secured using only potassium oxalate. The results are lower when the juice is clarified with lead acetate. With one exception, lead acetate followed by disodium phosphate gives the lowest results.

Potassium oxalate in the presence of lead acetate gives a less complete removal of lime than potassium oxalate alone. This is probably explained by the formation of a double salt of calcium plumbate which is slightly soluble and does not completely precipitate out.

There does not appear a direct proprotional agreement between the amount of lime and the amount of glucose, but it is shown that the presence of lime depresses the results. The results also indicate that clarification with lead acetate influences the result of the glucose determination.

The results of the study on the effect of lime may be summarized as follows:

The presence of potassium oxalate or disodium phosphate does not affect the reducing power of pure solutions.

The presence of lime in pure solutions of reducing sugars depresses the results. Removal of the lime with potassium oxalate restores the original reducing power.

The presence of lime causes low results in the regular Munson and Walker method as well as in the methylene blue method.

The removal of lime from clarified juices causes higher results to be secured for glucose.

Potassium oxalate is more efficient than disodium phosphate in removing lime.

It is indicated that neutral lead acetate clarification influences the results of the glucose determination in probably two ways: (1), incomplete removal of lime by potassium oxalate in the presence of lead, or (2), incomplete removal of lead.

Effect of the Presence of Lead on Glucose Determinations

The preceding work shows conclusively that the presence of lime causes low results. It also shows that potassium oxalate is a more efficient agent in removing lime than disodium phosphate. Some irregularities in results seemed to indicate that potassium oxalate might not be efficient in removing lead from solution. It seemed necessary to determine the effect of lead on the results and probably an efficient means for its removal.

The effect of lead in the solutions was first determined. Neutral lead acetate was added in varying amounts to molasses and pure solutions. The precipitate formed in the molasses due to the lead acetate was filtered off before the glucose was determined. The results are shown in the following table:

TABLE X

Material	cc. Lead Acetate (54° Brix)							
	Blank	0.2	0.4	0.5	1.0	1.5	2.0	3.0
	Gram reducing sugar							
Cane Sugar and Hydrolized Cane Sugar	.2131				.1805			
Dextrose	.1999				.2001			
Dextrose	.1901		.1894			.1866		
Levulose	.1832		.1827		.1822		.1785	
Molasses	.1086	.1066		.1042	.1023			.1026

The presence of excess lead in the solution causes low results. The presence of a comparatively small amount of lead produced a marked change in the result on the above molasses.

A comparison of the results obtained using potassium oxalate and disodium phosphate was made on several samples of molasses. The comparisons were made as follows: The samples were weighed out, dissolved and clarified with 3 cc. of 54° Brix neutral lead acetate. One portion of the filtrate was treated with 10 cc. of 10 per cent disodium phosphate and the glucose determined by the regular Munson and Walker procedure, and by titration using methylene blue as indicator. Another portion of the lead acetate clarified filtrate was treated with 10 cc. of 10 per cent potassium oxalate and the glucose determined by titration with methylene blue indicator. The results are listed below.

TABLE XI

Sample	Munson & Walker Method %	Methylene Blue Method: Potassium Oxalate %	Methylene Blue Method: Disodium Phosphate %	Difference Between Potassium Oxalate and Disodium Phosphate
1	.....	10.793	10.534	.259
2	.....	11.02	10.79	.22
3	24.28	24.28	24.28	.000
4	19.97	19.90	19.86	.040
5	.....	10.736	10.586	.150
6	11.37	11.15	11.08	.07
7	13.96	14.25	14.16	.09
8	16.29	16.40	16.33	.07
9	10.74	10.78	10.74	.04

The agreement between the two methods of analysis and between disodium phosphate and potassium oxalate in the methylene blue method is good in samples 3, 4 and 9 of the above molasses. The agreement is not so good in the other six samples. The differences between the treatment with potassium oxalate and disodium phosphate range from 0 to .26.

The following results show that similar differences are obtained with the Munson and Walker method when the two deleading agents are used:

TABLE XII

Sample No.	Deleading Agent: Potassium Oxalate %	Deleading Agent: Disodium Phosphate %	Difference
1	11.61	11.37	.24
2	11.09	10.74	.35
3	16.30	16.34	—.04
4	11.06	10.74	.32

In all but one of the above samples the potassium oxalate gives the higher results. Judging from preceding work it is probable that most of the difference is due to the presence of lime salts. It was found in the study of the effect of lime salts that if the solution of molasses was made distinctly ammoniacal before the disodium phosphate was added the lime was quite completely removed.

The following tests were designed to determine whether all of the difference between the two deleading salts was due to the removal of lime. A sample of molasses was clarified with neutral lead in the usual manner. One portion of the filtrate was treated with potassium oxalate, one with disodium phosphate, and the third made alkaline with ammonia and then treated with disodium phosphate, the results are as follows:

1. Potassium Oxalate .... 11.08 % Glucose
2. Disodium Phosphate .... 10.74 "
3. Made ammoniacal then adding Disodium Phosphate 11.20 "

An examination of the filtrates upon which the above test was made showed that the portion treated with potassium oxalate contained no trace of lime, but that an appreciable amount of lead was present. The disodium phosphate treatment showed the absence of lead, but a large amount of lime, while the portion which was made alkaline with ammonia contained no lead and but a trace of lime. This indicates that if the reaction of the solution is adjusted to the proper point disodium phosphate will remove the lime as well as the lead. These tests also indicate that both lead and lime cause low glucose results.

The above results indicated that possibly an excess of potassium oxalate was being used and that in the presence of this excess, soluble double salts of lead or lime were being formed which were not removed and which influenced the results. In the regular method about 3 cc. of 54° Brix neutral lead acetate is used for the clarification of 10 grams of molasses. Approximately .12 gram of neutral lead acetate and 1 gram of potassium oxalate, per gram of molasses, are used in the above procedure.

The following test was planned to determine the proper amount of each of the two salts necessary to remove lead, lime, or both, from molasses clarified in the above manner. Ten times the regular amount of molasses was weighed out and a proportional amount of neutral lead acetate was used for the clarification. Aliquots of this filtrate were measured out; one series was treated with potassium oxalate and the other series with disodium phosphate in amounts ranging from .01 gram to 3 grams per gram of molasses or per .12 gram of lead acetate. The lead and lime were determined qualitatively to determine the effective amount required for the most complete removal. The results are as shown below.

TABLE XIII

Grams	Potassium Oxalate		Disodium Phosphate	
Reagent	Lime	Lead	Lime	Lead
.01	Appreciable	Considerable	Considerable	Appreciable
.02	"	"	"	"
.04	"	"	"	"
.06	"	Appreciable	"	"
.08	"	"	"	"
.10	Decided Trace	Decided Trace	"	Decided Trace
.30	Slight "	Trace	"	Slight "
.50	None	"	"	None
1.0	"	Decided Trace	"	"
2.0	Trace	Appreciable	"	"
3.0	"	"	"	"

Potassium oxalate: When less than 0.1 gram is used appreciable quantities of both lead and lime remain in solution. The lime is quite completely removed with from 0.1 gram to 1.0 gram of potassium oxalate. Appreciable traces of lime again appear in the filtrate when more than 1.0 gram is used, the amount increasing as the concentration of potassium oxalate becomes greater.

Disodium phosphate: At the normal reaction of molasses disodium phosphate is not effective in removing lime. Lead is not completely removed with less than 0.1 gram; with 0.3 gram, or more, the lead is quite completely removed.

It was suggested that a mixture of the two salts might be better than one alone. This was tried in the following concentrations: 2 grams potassium oxalate with 8 grams disodium phosphate, and 3 grams potassium oxalate with 7 grams disodium phosphate per 100 cc. A qualitative test showed that the solutions treated with 10 cc. of either of these mixtures, contained neither lead nor lime.

A test was made to determine the effect of the above findings on glucose determinations. Three solutions were used. The first was a mixture of equal parts by weight of dextrose and levulose to which was added neutral lead acetate in amount equivalent to that used for molasses. Three molasses samples were used, clarified in the usual manner. The dextrose-levulose solution and the molasses filtrates were treated with varying amounts of potassium oxalate within the limits shown by the above test to be most efficient in removing both lead and lime.

TABLE XIV

Treatment	Dextrose and Levulose gms. Glucose	No. 1 Molasses % Glucose	No. 2 Molasses % Glucose	No. 3 Molasses % Glucose
Blank, no lead, .2 gm. Potassium Oxalate	.1949	23.237	20.641	11.293
Blank, lead not removed	.1834	......	......	......
Gm. Potassium Oxalate				
.05	.1889	......	......	10.341
.10	.1940	22.738	19.912	10.352
.20	.1947	22.851	20.299	10.771
.30	.1948	22.716	20.398	10.845
.40	.1947	22.763	20.426	10.770
.50	.1946	22.793	20.426	10.770
.60	.1943	......	......	10.845
.2 gm. Potassium Oxalate, .8 gm. Disodium Phosphate	.1948	22.948	20.456	10.968
.3 gm. Potassium Oxalate, .7 gm. Disodium Phosphate	.1947	22.899	20.451	10.971

The glucose results agree well with the results shown for the amounts of lead and lime present under the conditions of treatment. The figures for the pure dextrose and levulose mixture are practically constant and within limits of experimental error for amounts of potassium oxalate between .2 and .5 gram. A slight depression is indicated at .6 gram. The results with the two mixtures agree with those for potassium oxalate between .2 and .5 gram.

On molasses the results agree well between themselves, using amounts of .3 to .6 gram of potassium oxalate; with less than .2 gram, the results are all low. Also with less than .2 gram of potassium oxalate there were present traces of lime and appreciable amounts of lead. Between the range of .2 gram and .6 gram of potassium oxalate, lime was almost entirely absent, but there were present small traces of lead. It was deemed unnecessary to go beyond the limits given in the above table as preceding results had proved that the presence of lime or lead caused low results.

With the mixtures of the two salts the glucose results on the molasses are in good agreement but somewhat higher than those secured using potassium oxalate alone. Also the removal of lead and lime was more complete using the mixtures.

Further variations of the mixtures were tried on one sample of molasses. These mixtures consisted of 5 grams, 7 grams and 10 grams of each salt per 100 cc. The determinations were made on a separate weighing of the sample, so comparisons within minute quantities cannot be made directly with the above results. However, the results were in perfect agreement between themselves, and the filtrates showed complete removal of both lead and lime.

Under the conditions of the analytical procedure, the preceding tests show: (1) that both lead and lime depress the glucose results; (2) that disodium phosphate is efficient in removing lead, but does not satisfactorily remove lime; (3) that potassium oxalate removes lead and lime satisfactorily only within very narrow limits, more or less than the correct amount, leaves both in solution; (4) that a suitable mixture of the two salts removes both lead and lime satisfactorily.

Summary

1. Clarification with Lead Acetate:
   - a. Neutral lead acetate removes organic non-sugar reducing substances from molasses.
     - (1) The reducing substances removed from molasses are sufficient to materially affect the results in a glucose determination.
     - (2) The substances removed by neutral lead acetate reduce Soxhlet solution in the absence of other reducing sugars and increase the reduction in a pure dextrose or levulose solution.
     - (3) When freed from lead and added to a pure solution of dextrose or levulose these substances can be again removed by lead acetate and the original reducing power of the solution restored.
2. Lead causes low results and must be removed:
   - a. The presence of lead depresses the reducing power of pure dextrose and levulose.
   - b. The original reducing power is restored by removal of the lead.
   - c. The presence of lead causes low results in raw or clarified juice, syrup, raw sugar solutions and molasses.
3. Lime causes low results and must be removed:
   - a. The depressing effect upon the reducing power has been demonstrated in juice samples, molasses, pure hydrolized cane sugar, and in pure dextrose and levulose solutions.
   - b. The original reducing power is restored by removal of the lime.
4. Deleading and decalcifying agents:
   - a. Disodium phosphate.
     - (1) Completely removes lead from sugar solutions.
     - (2) Removes only very small amounts of lime from sugar solutions unless the solutions are made quite alkaline in reaction.
     - (3) When lead acetate and lime are added to sugar solutions the addition of disodium phosphate does not restore the original reducing power.
     - (4) An excess of disodium phosphate does not influence the results.
   - b. Potassium oxalate.
     - (1) Used in proper quantity completely removes lime from sugar solutions.
       - (a) When lime is added to pure sugar solutions the removal with potassium oxalate restores the original reducing power.
     - (2) Used in proper quantity removes all but traces of lead.
       - (a) The reducing power of sugar solutions to which lead and lime have been added is restored when the proper amount of potassium oxalate is used.
       - (b) In the presence of lead either a deficiency or an excess of potassium oxalate leaves lead and lime in solution and causes low results.
       - (c) In the absence of lead an excess of potassium oxalate does not influence the results.

c. Mixture of potassium oxalate and disodium phosphate.

(1) A mixture of the two salts in the proper amount satisfactorily removes both lead and lime from sugar solutions.

(a) Pure solutions to which lime and lead salts have been added, have the original reducing power restored when treated with the mixture.

(2) The proposed mixture for the method of analysis is: 3 grams potassium oxalate ($K_2C_2O_4$) and 7 grams disodium phosphate ($Na_2HPO_4.12H_2O$) in 100 cc. of distilled water.

(3) A mixture of the salts extends the range in which lead and lime are completely removed; a moderate excess of the oxalate under these conditions does not retain lead in solution as when used alone. The permissible excess which can be used in this manner is subject to further investigation.

5. Proposed methylene blue method for glucose determination:
The method as described in the *Record* (2) and reprint therefrom to be used with the following exceptions:

a. Preparation of samples: The concentration of glucose in the prepared sample should be such that 15 to 45 cc. of the solution, corresponding to 116 to 335 mgs. glucose per 100 cc. is required for titration. Preferably the amount should be from 25 to 40 cc. or 125 to 200 mgs. glucose per 100 cc.

(1) Juices: For control purposes the juices should be clarified with the smallest possible amount of neutral lead acetate, and an aliquot of the clarified sample treated with 10 cc. mixed oxalate-phosphate solution and again filtered with Kieselguhr. The filtrate is used for the titration. For agricultural or field work, the error due to the non-sugar reducing substances in juices would be small and lead acetate clarification could be omitted, also the amount of lime in the raw juice would be slight, the combined effect of these salts would be small, so that an aliquot of the juice after Kieselguhr filtration could be titrated direct.

(2) Molasses: 10 cc. of the mixed oxalate-phosphate solution substituted for disodium phosphate after neutral lead acetate clarification.

(3) Syrup and raw sugar: The procedure for glucose determination would be similar to that for molasses.

b. Analysis: To be made as previously described, with whatever further details may be necessary.

c. Calculations of results: To be made as described. An addition to the published table of factors may be advisable for use with syrup and raw sugars.

The above summary of this work was presented at the meetings of the Association of Hawaiian Sugar Technologists, October 17 to 20, 1927, with a proposal that the methylene blue method be adopted by the Association as the official

method for glucose determinations. The method was recommended for adoption on the basis of experience with the method in this laboratory and on the work which is presented herewith. This work had been completed but a few days before the meetings, so that a detailed report was not possible at that time.

It is proposed that the committee appointed for this purpose draw up a detailed procedure for the determination of glucose based on the above findings; that the method set forth definite specifications for the amount of neutral lead acetate to be used for the clarification of the sample and also the amount and nature of deleading and decalcifying agent.

Methods for the determination of glucose do not specify the amount of neutral lead acetate to be used for clarification of the products, but state, "clarify with neutral lead acetate, avoiding an excess." Experience in this laboratory, covering a large variety of juices and molasses from practically all plantations in the Islands, indicates that 3 cc. of 54° Brix neutral lead acetate is sufficient for the clarification of 10 grams of molasses, and that 1 cc. is sufficient for mill juices and raw sugar. For this amount of lead acetate a definite mount of deleading and decalcifying agent should be specified. If such a specification is made we believe that the phosphate-oxalate mixture proposed will satisfactorily remove both lead and lime from the solution, thus avoiding the errors due to their presence.

Acknowledgment

The writer wishes to extend acknowledgment to Dr. F. E. Hance for valuable suggestions in the treatment of the lead acetate percipitate from molasses.

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Sugar Prices

96° Centrifugals for the Period September 16 to December 15, 1927

Date	Per Pound	Per Ton	Remarks
Sept. 16, 1927......	4.86¢	$97.20	Cubas.
" 19...........	4.83	96.60	Cubas.
" 23...........	4.77	95.40	Cubas.
" 27...........	4.74	94.80	Cubas.
Oct. 3...........	4.71	94.20	Cubas.
" 4...........	4.65	93.00	Philippines.
" 10...........	4.565	91.30	Cubas, 4.55; Philippines, 4.58.
" 11...........	4.65	93.00	Cubas.
" 13...........	4.71	94.20	Cubas.
" 18...........	4.65	93.00	Cubas.
" 21...........	4.665	93.30	Cubas, 4.68, 4.65.
" 25...........	4.71	94.20	Porto Ricos.
" 26...........	4.68	93.60	Cubas.
" 31...........	4.65	93.00	Cubas.
Nov. 2...........	4.58	91.60	Cubas.
" 9...........	4.65	93.00	Cubas.
" 14...........	4.71	94.20	Cubas.
" 18...........	4.65	93.00	Cubas.
" 28...........	4.58	91.60	Cubas.
" 30...........	4.52	90.40	Cubas.
Dec. 8...........	4.58	91.60	Cubas.
" 10...........	4.61	92.20	Cubas.
" 12...........	4.58	91.60	Cubas.
" 14...........	4.595	91.90	Cubas, 4.58, 4.61.
" 15...........	4.61	92.20	Cubas.